SUMMARY
OF
RESEARCH
2001

Department of Oceanography
Graduate School of Engineering and Applied Sciences

Mary L. Batteen
Chair

Jeffrey D. Paduan
Associate Chair for Research

20030709 032

Naval Postgraduate School
Monterey, California 93943-5138

NPS-09-02-025

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NAVAL POSTGRADUATE SCHOOL
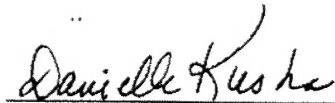**Monterey, California**

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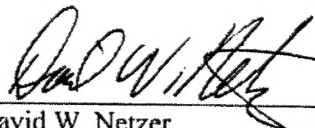This report was prepared for the Naval Postgraduate School, Monterey, CA.

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Director, Research Administration

David W. Netzer
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13. ABSTRACT (Maximum 200 words.)

This report contains project summaries of the research projects in the Department of Oceanography. A list of recent publications is also included, which consists of conference presentations and publications, books, contributions to books, published journal papers, and technical reports. Thesis abstracts of students advised by faculty in the Department are also included.

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THE NAVAL POSTGRADUATE SCHOOL MISSION

Increase the combat effectiveness of the U.S. and allied forces and enhance the security of the U.S.A. through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense related challenges of the future.
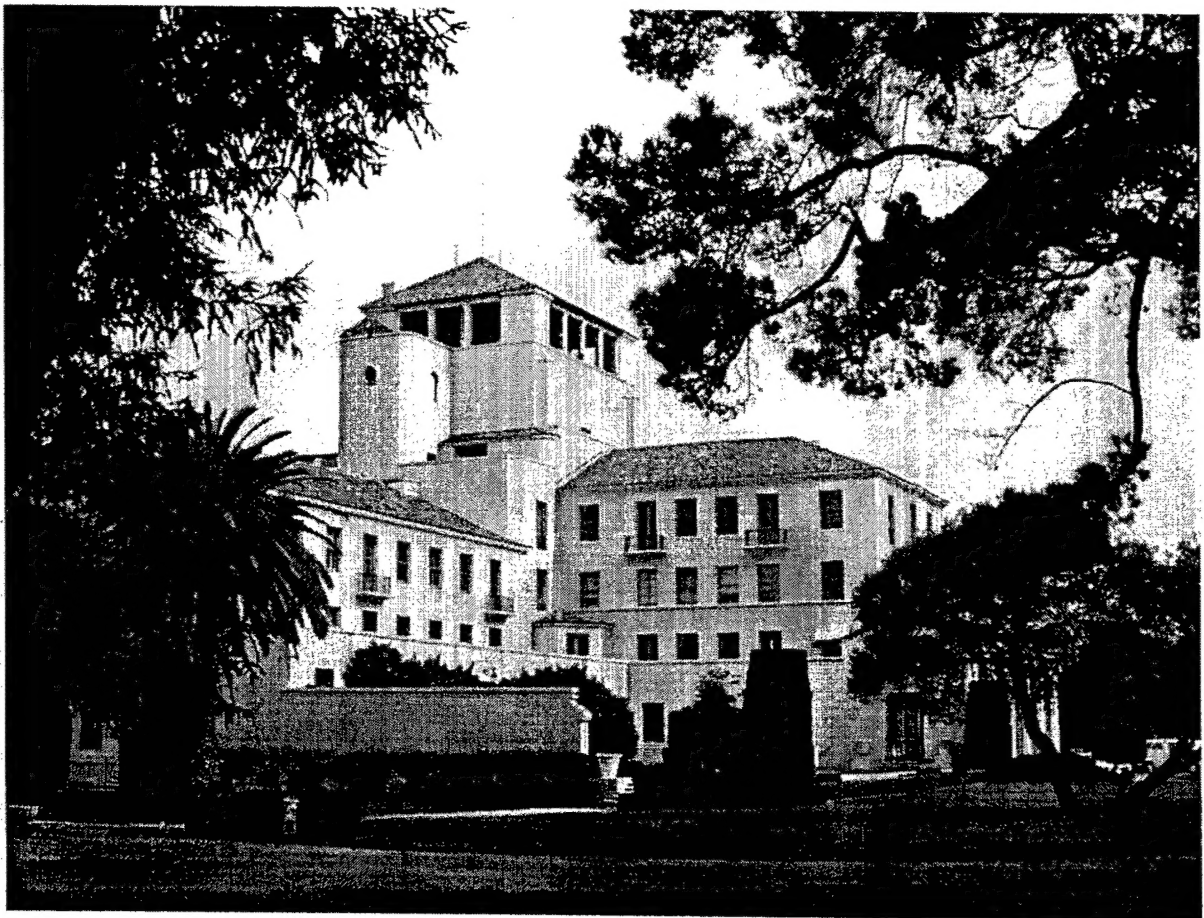
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PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the four graduate schools (School of International Graduate Studies, Graduate School of Operations and Information Sciences, Graduate School of Engineering and Applied Sciences, and Graduate School of Business and Public Policy) and three Research Institutes (The Modeling, Virtual Environments, and Simulation (MOVES) Institute, Institute for Information Superiority and Innovation (I2SI), and Institute for Defense System Engineering and Analysis (IDSEA). This volume contains research summaries for the projects undertaken by faculty in the Department of Oceanography during 2001. The summary also contains thesis abstracts for those students advised by Oceanography faculty during 2001.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the Naval Postgraduate School Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2099 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, http://web.nps.navy.mil/~code09/

Additional published information on the Naval Postgraduate School Research Program can be found in:

- *Compilation of Theses Abstracts:* A quarterly publication containing the abstracts of all unclassified theses by Naval Postgraduate School students.

- *Naval Postgraduate School Research*: A tri-annual (February, June, October) newsletter highlighting Naval Postgraduate School faculty and student research.

- *Summary of Research*: An annual publication containing research summaries for projects undertaken by the faculty of the Naval Postgraduate School.

> This publication and those mentioned above can be found on-line at:
> http://web.nps.navy.mil/~code09/publications.html.

INTRODUCTION

The research program at the Naval Postgraduate School exists to support the graduate education of our students. It does so by providing military relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, and maintains the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focused graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at the Naval Postgraduate School consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with government laboratories and universities, provides off-campus courses either on-site at the recipient command, by VTC, or web-based, and provides short courses for technology updates.

- Naval Postgraduate School Institutionally Funded Research (NIFR) Program: The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursably sponsored, and (4) to cost-share the support of a strong post-doctoral program.

In 2001, the level of research effort overall at the Naval Postgraduate School was 148 faculty work years and exceeded $48 million. The reimbursable program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY2001, over 93% of the research program was externally supported. A profile of the sponsorship of the Naval Postgraduate School Research Program in FY2001 is provided in Figure 1.

Navy
53%

Army
11%

Defense
8%

Other-Federal
7%

CRADA
1%

Other
2%

National Science
Foundation
3%

Joint
4%

Air Force
5%

Institutional
6%
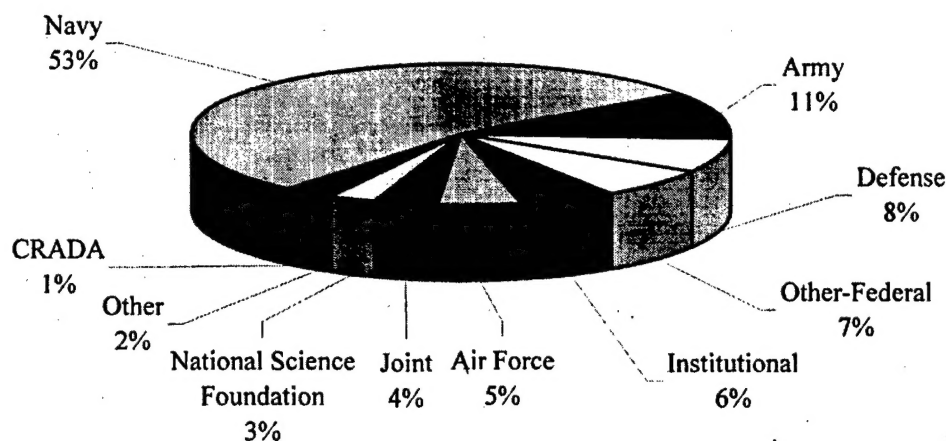
Figure 1. Profile of NPS Research and Sponsored Programs ($52M)

The Office of Naval Research is the largest Navy external sponsor. The Naval Postgraduate School also supports the Systems Commands, Warfare Centers, Navy Labs and other Navy agencies. A profile of external Navy sponsorship for FY2001 is provided in Figure 2.

Warfare Centers
15%

Other
14%

ONR
24%

CNO
8%

USMC
1%

NAVAIR
7%

NAVSPACE
1%

NRL
2%

NAVSEA
3%

CDTEMS
3%

CNET
4%

SPAWAR
6%

Navy TENCAP
3%

NETSAFA
4%

NSGC/NELO/
NIWA
5%
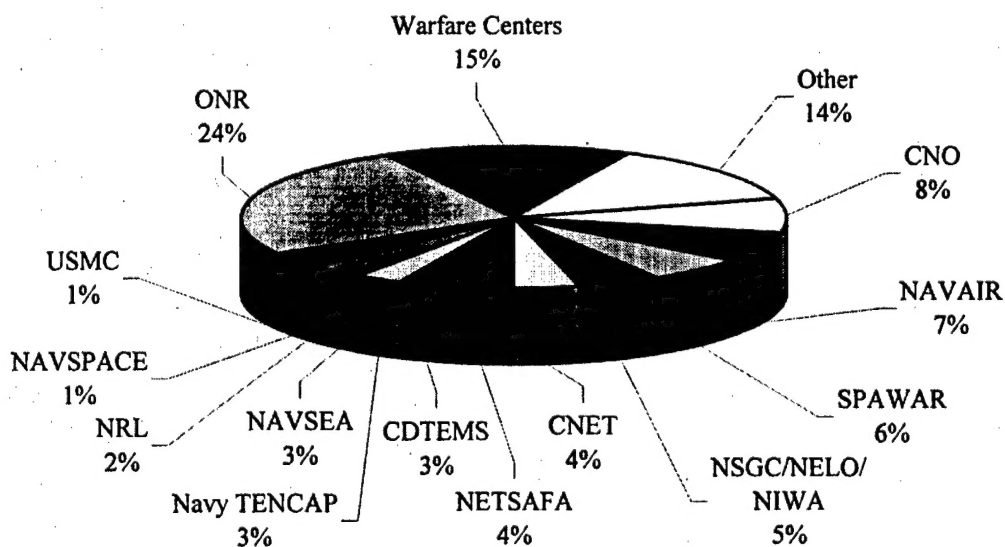
Figure 2. Navy External Sponsors of NPS Research and Sponsored Programs ($29M)

These are both challenging and exciting times at the Naval Postgraduate School and the research program exists to help ensure that we remain unique in our ability to provide education for the warfighter.

DAVID W. NETZER
Associate Provost and Dean of Research

September 2002

DEPARTMENT OF OCEANOGRAPHY

MARY L. BATTEEN
CHAIR

DEPARTMENT SUMMARY

OVERVIEW:

The Department of Oceanography has developed a broad research program focused on physical oceanography to meet the anticipated future needs of the Navy. Our basic research themes are the development of scientific capabilities to measure, analyze, and forecast fields of littoral ocean variables, which occur in association with synoptic/mesoscale processes over limited regional temporal domains. The areas of emphasis include coastal and nearshore ocean dynamics, air-sea interaction phenomena and boundary currents. Regions of interest include the polar seas, coastal ocean regions and strategic straits of the world.

Our applied research themes are the application of analyses and forecasts of upper ocean synoptic/mesoscale variability to Naval operations. Areas of emphasis include the impact of littoral processes, eddies and boundary currents on ocean surveillance systems, the effect of coastal ocean response to storms on acoustic propagation and ambient noise and the impact that the wave climate exerts on nearshore processes and beach character as it pertains to mine/mine countermeasure and amphibious warfare.

These research themes require the development of numerical ocean prediction and synoptic oceanography capabilities. They are achieved through employment of modern dynamical and mathematical principles, numerical and statistical methods, computational and graphical facilities, and in-situ and remote sensing observations.

CURRICULA SERVED:

- Meteorology and Oceanography
- Operational Oceanography
- Oceanography
- Undersea Warfare
- Space Systems Operations
- Space Systems Engineering

DEGREES GRANTED:

- Master of Science in Meteorology and Physical Oceanography
- Master of Science in Physical Oceanography
- Doctor of Philosophy

RESEARCH THRUSTS:

- Acoustical Oceanography:
  Professor Ching-Sang Chiu, Emeritus Professor Robert Bourke, Assistant Professor Arthur Parsons, Research Professor James Wislon
- Air-Sea Interaction and Ocean Turbulence:
  Professor Roland Garwood, Research Associate Professor Tim Stanton, Professor Peter Chu, Professor Le Ly
- Coastal and Nearshore Oceanography:
  Associate Professor Jeff Paduan, Distinguished Professor Ed Thornton, Associate Professor Thomas Herbers, Research Assistant Professor Edith Gallagher, Assistant Professor Pierre Poulain, Professor Curt Collins, Research Professor Steve Ramp, Research Associate Professor Leslie Rosenfeld
- Numerical Prediction and Data Assimilation:
  Associate Professor Mary Batteen, Professor Bert Semtner, Research Associate Professor Julie McClean, Research Assistant Professor Robin Tokmakian, Research Assistant Professor Ramsey Harcourt, Research Associate Professor Wieslaw Maslowski, Assistant Professor Pierre Poulain, Senior Lecturer Arlene Guest, Research Associate Professor Le Ly

- GI&S and Navigation: Research Professor James Clynch, Assistant Professor Arthur Parsons
- Polar Oceanography:
  Research Associate Professor Wieslaw Maslowski, Research Assistant Professor Yuxia Zhang, Emeritus Professor Robert Bourke, Professor Roland Garwood, Research Assistant Professor Ramsey Harcourt

RESEARCH FACILITIES:

- Research Vessel *Point Sur*
- Ocean Acoustic Observatory at Point Sur
- Computer Graphics Laboratory
- Moored Equipment Laboratory
- Calibration Laboratory
- Tactical Environmental Support Laboratory

RESEARCH CHAIR:

- Office of Naval Research Chair in Arctic Marine Science

RESEARCH PROGRAM (Research and Academic)-FY2001:

The Naval Postgraduate School's sponsored program exceeded $49 million in FY2001. Sponsored programs included both research and educational activities funded from an external source. A profile of the sponsored program for the Department of Oceanography is provided below:

Navy 70%

NSF 20%

Other-Federal 6%

Other 4%
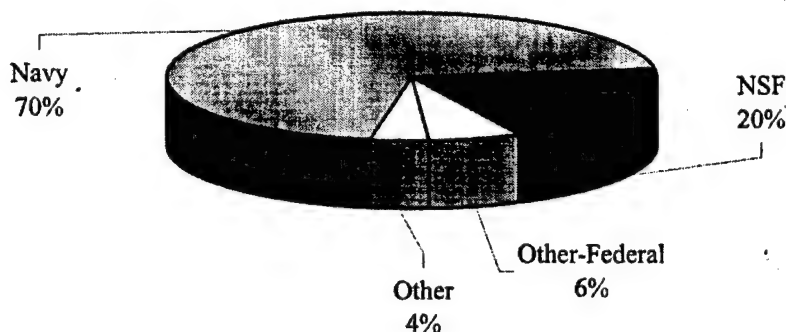
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ONR CHAIR IN ARCTIC MARINE SCIENCE
Robert H. Bourke, Professor Emeritus
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The Chief of Naval Research has established at the Naval Postgraduate School a Chair in Arctic Marine Science. The objectives of the Chair are to foster oceanographic research in the Arctic, acquaint naval officer students with Arctic problems, reduce results of pure research to operational usage, and publicize Navy interest in the Arctic.

SUMMARY: Professor Bourke served as administrator of the Chair handling such details as selecting Chair candidates, writing IPAs and proposals and setting up visits and seminars for the Chair incumbent.

Professor Ursula Schauer from the Alfred Wegener Institute for Polar and Marine Research was the Chairholder during FY01. While at NPS Dr. Schauer analyzed data and drafted papers based on two data sets acquired in Fram Strait. She examined three years of high resolution current meter and temperature data from buoys spread across Fram Strait. This data provided an initial sense of the variability of the volume and heat flux into and out of the Arctic Ocean. Based on a series of observations carried out through a number of European programs conducted in the 1990s, she determined the flux of Atlantic Water to the Arctic Ocean and its modifications enroute along two pathways leading to the central Arctic Ocean. She also provided several lectures to the Polar Oceanography course and gave a series of seminars to the Department faculty.

A search was conducted for the follow-on Chairholder. Prof. Mark A. Johnson from the University of Alaska has been selected. He will be in residence from October 2001 to September 2002 and will conduct work on modeling the Arctic atmosphere, sea ice and ocean as a coupled system to understand climatic changes.

DoD KEY TECHNOLOGY AREAS: Battlefield Environments

KEYWORDS: Arctic Ocean, Fram Strait, Barents Sea, Atlantic Water

COUPLED OCEAN ACOUSTICS AND PHYSICAL OCEANOGRAPHY OBSERVATIONS IN THE SOUTH CHINA SEA: THE NPS ACOUSTIC COMPONENT
Ching-Sang Chiu, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVES: This effort is part of a large, international program called the Asian Sea International Acoustic Experiment (ASIAEX). In collaboration and coordination with other U.S. and Asia investigators participating in ASIAEX, comprehensive measurements and analysis were being carried out of the different oceanographic factors affecting low frequency (< 600 Hz) acoustic propagation in a shelfbreak region in the Northeastern South China Sea (SCS). Specifically, the NPS acoustic research objectives are: 1) To understand the physics, variability and predictability of low-frequency sound pulse propagation along and across the NE SCS shelfbreak, including the dependence on frequency, source depth and path orientation, and the relations to water-column, bathymetric and sub-bottom structures. 2) To expand the acoustic knowledge acquired from previous shelf-slope experiments including shelfbreak PRIMER and SWARM, with added emphases on the horizontal properties of the sound field. 3) To investigate the advantages and disadvantages of conducting shallow-water tomography using higher-frequency (> 400 Hz) transmissions. 4) To formulate and test a phase or time-based modal tomography inverse method for joint estimations of the water-column and sediment properties.

SUMMARY: The main field program was a huge success. It was executed from 25 April to 27 May 2001 by approximately 20 principal investigators from three different countries, U.S., Taiwan and Singapore, using three Taiwanese research vessels *FISHERIES RESEARCHER 1* (FR1), *OCEAN RESEARCHER 1* (OR1) and *OCEAN RESEARCHER 3* (OR3). The simultaneous, high-resolution observations of the acoustic propagation characteristics and water column properties was accomplished by a combination of

moored and shipboard observations. The NPS team was primarily involved in the preparation, design, deployment, and recovery of the moored network. This network consisted of a total of 27 environmental moorings and 6 acoustic moorings stretching the pre-designed across and along-shelf mooring lines. The centerpiece of this observational network was an L-shaped hydrophone array that was put together by WHOI and NPS. This listening array consisted of 32 hydrophones spanning 472 m along the bottom and 16 hydrophones moored vertically in the water column. These hydrophones sampled at 3.2 kHz continuously for three weeks and collected 600 gigabytes of data. These data are still being quality controlled, backed up and distributed to the participating institutions. The processing and analysis of the entire acoustic data set, in conjunction with the oceanographic data, is currently underway with goal to understand the influences of inherent ocean variability on acoustic propagation, coherence and predictability.

PUBLICATIONS:

Chiu, C.-S., S. R. Ramp and J.F. Lynch, The ASIAEX 2000 preliminary experiment in the East China Sea (ECS), *Proceedings of the Fifth International Conference in Theoretical and Computational Acoustics*, Beijing, China, 2001. (Invited Paper)

Colosi J.A., J.F. Lynch, R.C. Beardsley, G. Gawarkiewicz, C.-S. Chiu and A. Scotti, Observations of nonlinear internal waves on the New England continental shelf during summer shelfbreak, *PRIMER*, *Journal of Geophysical Research*, 106(C5), 9587-9601, 2001.

PRESENTATION:

Chiu, C.-S., Sound speed fluctuation statistics in the South China Sea, Asian Sea International Acoustics Experiment (ASIAEX) Workshop, Maui, HI, 31 October–2 November 2001.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments

KEYWORDS: Littoral, Acoustics, Shelfbreak

DETERMINATION OF THE DETECTION AND CLASSIFICATION PROBABILITIES AND RANGE LIMITS OF INEXPENSIVE ACOUSTIC SENSORS AND DATA PROCESSING TECHNIQUES FOR MONITORING ODONTOCETI WHALES

Ching-Sang Chiu, Professor
Curtis A. Collins, Professor
Department of Oceanography
Sponsor: Chief of Naval Operations (N45)

OBJECTIVE: To realistically determine the effectiveness of simple and cost-effective sonar systems (sensors and processing techniques) for monitoring toothed whales (odontoceti) in areas with diameters smaller than a few kilometers. Sensors to be evaluated include sonobuoy array, short-aperture suspended arrays, and bottom-mounted arrays. Processing methods to be considered include Energy detectors for transient signals, a matched-signal method employing a fast, analytic propagation model for localization and signal deverberation over a small area, correlation classifiers and wavelet based methods.

SUMMARY: The approach is to design and conduct controlled at-sea experiments to derive quantitative performance measures: probability of detection and classification, probability of false detection and classification, and range limits.

A digital audio library of available odontocete calls was collected and representative calls were selected for playback experiments at sea. Two at sea deployments were conducted in July and November 2001. The selected whale signals were transmitted from both G34 and J9 transducers to SSQ-57B sonobuoys at ranges of 1-5 km. The experiment was conducted in both shallow (<300m) and deep (>1500m) water depths with the source and receivers varied between 30 and 125m. Each call was played at

ten-minute intervals for three hours at each source depth to study the statistical variation during the analysis.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Sensors

KEYWORDS: Marine Mammal, Passive Acoustic Detection

UNCERTAINTIES AND INTERDISCIPLINARY TRANSFERS THROUGH THE END-TO-END SYSTEM (UNITES)
Ching-Sang Chiu, Professor
Department of Oceanography
Sponsors: Office of Naval Research

OBJECTIVE: This effort is part of a multi-institutional team effort to capture uncertainty in the common tactical picture. The team's name is UNITES, which stands for UNcertainties and Interdisciplinary Transfers through the End-to-End System. The UNITES team, with expertise spanning the ocean environment, underwater acoustics and tactical sonar systems, consists of a total of twelve principal investigators from nine different organizations including Harvard University (HU), the Naval Postgraduate School (NPS), and the OASIS, Inc. The NPS component in the UNITES team's paradigm to solve the interdisciplinary, end-to-end problem has two objectives: 1) To characterize acoustic prediction uncertainties, including their connections to the uncertainties in the ocean and geo-acoustic parameter estimates. 2) To forecast and improve acoustic baselines and their uncertainties in a data-assimilation framework involving coupled ocean and acoustic state variables.

SUMMARY: The research focuses on a shelfbreak environment, encompassing the outer continental shelf and the continental slope, where the physical oceanography, specifically the shelfbreak front, internal tides and internal solitary waves, play a significant role in introducing acoustic prediction uncertainty at multiple time and space scales. The acoustic prediction uncertainty is further complicated by the variable bathymetry and inhomogeneous sediment properties as the water-column variability shifts the insonified bottom locations from time to time. In close collaboration with HU and based on Error Subspace Statistical Estimation (ESSE), a methodology for the modeling and prediction of coupled ocean physics and acoustic uncertainties was developed and tested with the Shelfbreak PRIMER data. The test was a case study of the linkage between ocean mesoscale uncertainties and acoustic wavefield uncertainties in a slope-to-shelf transmission across the MAB shelfbreak front.

PUBLICATION:

Lermusiaux, P.F.J., C.-S. Chiu and A.R. Robinson, Modeling uncertainties in the prediction of the acoustic wavefield in a shelfbeak environment, *Proceedings of the Fifth International Conference in Theoretical and Computational Acoustics*, Beijing, China, 2001. (Invited Paper)

PRESENTATION:

Lermusiaux, P.F.J., C.-S. Chiu and A.R. Robinson, Coupled physical-acoustical data assimilation and prediction of uncertainties in a shelfbreak environment, Thirty third International Liège Colloquium on Ocean Dynamics, Liège, Belgium, 7-11 May 2001.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Sensors

KEYWORDS: Environmental Uncertainties, Acoustic Uncertainties, Sonar Performance

MINE IMPACT BURIAL SENSITIVITY STUDY
Peter C. Chu, Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVES: This proposal is to assess current Navy's Impact Burial Prediction Model (IBPM). The most recent version of the IBPM (i.e., IMPACT25) will be integrated and it will be used to compare predicted burial against a descriptive mapping from grain size to impact burial developed by NAVOCEANO. Core data will be obtained from NAVOCEANO for this study. This comparison will help assess the need for improvements to the IBPM and whether the NAVOCEANO mapping is adequate for Naval operations use. This is a continuation of a series of recent NPS thesis studies on mine burial.

SUMMARY: A series of mine drop experiments with different sizes of model mines were conducted at NPS and Naval Surface Warfare Center to obtain a complete dataset for depicting the mine movement in the water column:

Analysis on the data collected from the Mine Impact Burial Experiment (MIBEX). This experiment was designed to collect synchronous mine impact burial and environmental data. The experiment was conducted on 23 May 2000 at the site of the Monterey Inner Shelf Observatory (MISO) off of Del Monte Beach in Monterey Bay (Smith 2000). The model mine is a 55 gallon drum filled with sand to give it a uniform density. During the experiment, 17 gravity cores were obtained. The oceanic environmental parameters were recorded at MISO. The burial depth was measured by the divers. The mine impact and environmental (water column and sediment) data were analyzed in FY01.

Mine Drop Experiment (MIDEX) at the NPS swimming pool. MIDEX basically consisted of dropping each of three right cylinders into the water where each drop was recorded underwater from two viewpoints. The controlled parameters for each drop were: center of mass position (COM), initial velocity (Vinit), drop angle and the ratio of mine's length to diameter.

A synchronized data set of ocean environment (including waves, currents, and bottom shear strength) and mine burial depth was established on the base of the Mine Impact Burial Experiment (MIBEX). A technical report depicting this dataset was published by NPS and widely distributed into the minewarfare community.

Mine Drop Experiment (MIDEX) was conducted in June 2001 at the NPS swimming pool with 1/20 scale model mines. Around 500 mine drops were completed with different mine parameters (L/D, COM) and drop conditions (angle and velocity). Upon completion of the drop phase, the video from each camera was converted to digital format and a dataset for mine movement in the water column was established.

Mine test experiment at Carderock was completed. LCDR Ashely Evans participated the experiment and started the data analysis.

The hydrodynamic system depicting the movement of rigid body (such as mine) in the water column has been established on the base of balance of momentum and moment of momentum. This system consists of nine nonlinear equations. Among them, three equations depict the acceleration of the center of mass; three equations depict the moment of momentum balance, and three equations predict the three Euler angles of the mine. This hydrodynamic system does not have analytical solutions due to the nonlinearity. A numerical model is being built to solve the problem.

Workshop was conducted on ONR Expert System Program on Mine Impact Burial Prediction at NPS on 10 January 2001. The MIBEX dataset was transferred to the ONR Expert System group.

The dynamic system (nine nonlinear equations) for the mine movement has the potential impact on the nonlinear dynamics. The hydrodynamics of mine impact in water column can be applied to a general scientific problem of the fluid-rigid body interaction including stability and chaotic motion.

The datasets obtained from three consecutive experiments, MIBEX, MIDEX, and Mine testing at Carderock, will impact the scientific and Naval minewarfare communities on the mine movement in the water column.

The results obtained from this project are transferred to the Naval Oceanographic Office, COMINEWARCOM, and the ONR Mine Impact Burial Prediction group. Two major weaknesses in water phase of IMPACT25 (tumbling of mine and no moment of momentum balance) are well accepted by the minewarfare community. The datasets collected from MIBEX and MIDEX will greatly impact on the development of an accurate Mine Impact Burial Prediction Model. The data were also used for

development of the Expert System for Mine Impact Burial at the Applied Physics Laboratory of the John Hopkins University and the Environmental Sciences Department of the University of Virginia.

PUBLICATIONS:

Chu, P.C., T.B. Smith and S.D. Haeger, "Mine Burial Impact Prediction Experiment," Naval Postgraduate School Technical Report, NPS-IJWA-01-007, pp.161, 2001.

Chu, P.C., A. Gilless, C.W. Fan and P. Fleischer, Hydrodynamic characteristics of falling cylinder in water column, *Advances in Fluid Mechanics*, 2001, in press.

Chu, P.C., T.B. Smith and S. Haeher, Mine impact burial prediction experiment, *Journal of Counter-Ordinance Technology*, 2001, submitted.

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Cintron, C., "Verification of an Operational Acoustic Model (CASS-GRAB) in Mine Hunting Application," Masters Thesis, Naval Postgraduate School, March 2001.

DoD TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Modeling and Simulation

KEYWORDS: Mine Impact Burial, Shear Strength, Moment of Momentum, Sediment Type

SOUTH CHINA SEA AND JAPAN SEA MODELING
Peter C. Chu, Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVES: This is a multi-year project. Under the current sponsorship the following research has been completed: an optimization scheme for determining open boundary conditions, high-order difference schemes for reducing sigma coordinate error at abrupt topography, a statistical model for determining thermohaline variability, and a parametric model for obtaining physical characteristics (SST, mixed layer depth, thermocline depth, thermocline strength, etc.) from vertical profiles. It is proposed to incorporate these new techniques into the South China Sea prediction system (POM) and to expand the modeling effort into a coastal air-ocean coupled model.

SUMMARY: (1) A coastal atmosphere-ocean coupled system (CAOCS) is developed. The oceanic component consists of the Princeton Ocean Model (POM) with 20 km horizontal resolution and 23 sigma levels conforming to a realistic bottom topography. The atmospheric component consists of a recent version of the regional climate model (RegCM2) with 40 km horizontal resolution and 16 vertical levels. The CAOCS model was integrated for a month from 1 May 1995. The initial conditions for the atmosphere are the ECMWF analyses, and for the ocean are the model output from a forty four months' run of the stand-alone POM model forced by climatological monthly mean wind stresses, and restoring type surface salt and heat. The CAOCS model agrees well with an extensive airborne expendable bathythermograph (AXBT) survey of the South China Sea (SCS) conducted in May 1995, and shows the capability of simulating the SCS multi-eddy structure in May 1995.

(2) A variational P-vector method was developed to invert the velocity field. The GDEM for the JES was built up on historical (1930-1997) 136,509 temperature and 52,572 salinity profiles. The climatological mean and seasonal variability of the current systems are well inverted especially the Tsushima Warm Current (TWC) and its bifurcation, the East Korean Warm Current\ (EKWC), the Japan Nearshore Branch (JNB), the confluence of the EKWC and the North Korean Cold Current (NKCC) near the Korean coast and flows northeastward along the subpolar front, and a mesoscale anticyclonic eddy in the Ulleng/Tsushima Basin. Furthermore, this method has the capability to invert flow reasonably well across the shallow straits such at the Tsushima/Korea, Tsugaru, and Soya Straits. The GDEM temperature and salinity and the inverted velocity fields provide a balanced initial fields for JES numerical modeling and simulation.

(3) A geometric model has been developed for determination of subsurface thermal structure from satellite sea surface temperature observations. Based on a layered structure of temperature fields (mixed-layer, thermocline, and lower layers), the parametric model transforms a vertical profile into several parameters: sea surface temperature (SST), mixed layer depth (MLD), thermocline bottom depth (TBD), thermocline temperature gradient (TTG), and deep layer stratification (DLS). These parameters vary on different time scales: SST and MLD on scales of minutes to hours, TBD and TTG on months to seasons, and DLS on an even longer time scale. If the long time scale parameters such as TBD, TTD, and DLS are known (or given by climatological values), the degree of freedom of a vertical profile fitted by the model reduces to one: SST. When SST is observed, we may invert MLD, and, in turn, the vertical temperature profile with the known long time scale parameters: TBD, TTG, and DLS.

(4) The South China Sea warm-core/cool-core eddies were identified using the Navy's MOODS data as well as the National Meteorological Center (NCEP) sea surface temperature (SST) fields (1982-94).

(5) The sigma-coordinate, pressure gradient error depends on the choice of difference schemes. By choosing an optimal scheme, we may reduce the error in a great deal without increasing the horizontal resolution. Several high-order schemes were developed.

(6) Haney-type surface thermal boundary conditions connect net downward surface heat flux to air/sea temperature difference (gradient-type condition) or to climate/synoptic sea temperature difference (restoring-type condition). On the basis of cross-correlation and variance analyses on the net downward surface heat flux and air/sea temperature data from global coupled atmosphere-ocean model, we obtain the following results: (i) The restoring-type conditions do not represent the surface thermal forcing anywhere in the world oceans. (ii) For the equatorial and subtropical oceans, the gradient-type conditions are not good approximations for the surface thermal forcing. (iii) For the middle and high latitudes away from coasts, the gradient-type conditions are good approximation for the surface thermal forcing.

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PRESENTATIONS:

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Chu, P.C. and C.W. Fan, Isopycnal surface circulation in water mass crossroads, Joint Assembles of the International Association for Physical Sciences of the Oceans, International Association for Biological Oceanography, Mar del Plata, Argentina, 22-26 October 2001.

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Chu, P.C., L.M. Ivanov, T.P. Korzhova, T.M. Margolina and O.V. Melnichenko, Reconstruction of ocean currents from sparse and noisy data in an open domain, Joint Assembles of the International Association for Physical Sciences of the Oceans, International Association for Biological Oceanography, Mar del Plata, Argentina, 22-26 October 2001.

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DoD TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Modeling and Simulation

KEYWORDS: P-vector, Geostrophic Velocity, Beta-Spiral, Inverse Method, Primitive Equation Model, Turbulence Closure, High-Order Difference Schemes, Predictability Density Function

THEORETICAL ANALYSIS OF PREDICTABILITY AND SENSITIVITY FOR OCEAN CIRCULATION MODELS
Peter C. Chu, Professor
Department of Oceanography
Sponsor: Naval Oceanographic Office

OBJECTIVES: The objective of this project is to develop a spectral approach for the assimilation of drifting buoy data into eddy-resolution regional circulation models. The approach is based on the analysis of the principle components of Fisher's Information Matrix (FIM) constructed from a knowledge of the model, area and sources of the bias of Eulerian statistics calculated by Lagrangian data. To obtain a relation between the Eulerian and Lagrangian statistics a model of buoy dynamics is used in statistically inhomogeneous non-Gaussian eddy velocity field with a finite correlation time. It's demonstrated that the approach is applicable for known and unknown open boundary conditions and is robust to the variations of sizes of observation samplings. The knowledge of FIM allows to formulate requirements to properties of assimilation procedure (assimilation strategy) and quality of Lagrangian data to achieve the maximum improving of model now/forecast skill. The approach is examined through the assimilation of the synthetic and real drifter data into the regional oceanographic models of the Gulf of Mexico and Japan/East Sea.

SUMMARY: A new theoretical approach was developed to quantitatively evaluate predictability of regional and basin-scale eddy-resolving numerical models and applied this approach to analyze the forecast skill of Princeton Ocean Model. The quantitative criterion for estimating forecast skill was also established.

The planned work was completely finished. First, the special iteration technique was developed on the base of Ivanov et al. (1994) for analytical estimations. Second, a new power law was found for the second kind of predictability applying our approach to verify numerical model results by the drifter buoy data. Such a power law allows the reformulation of the predictability theory and to introduce a new concept of "extreme prediction." Third, the statistics of the extreme predictions may considerably improve the prediction skill of ocean models. Fourth, several quantitative measures of the prediction skill have been suggested and examined. All these measures are based on the definition of the first passage time. The usefulness of the first-passage time is demonstrated in various ocean models. Fifth, a special procedure was developed for reconstructing circulation from sparse and noisy data in domains with open boundaries. The technique was successfully used to the nowcast of daily circulation on the Louisiana-Texas shelf reproduced from the SCULP-1 drifter data and LATEX moored current meter data.

PUBLICATIONS:

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DoD TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Modeling and Simulation

KEYWORDS: Valid Prediction Period, First-Passage Time, Fokker-Planck Equation, Tolerance Level, Error Growth

GPS ANTARCTIC LANDING SYSTEM:
LANDING SYSTEMS COMMITTEE STUDIES
James R. Clynch, Research Professor
Department of Oceanography
Sponsor: Space and Naval Warfare Systems Center - Charleston

OBJECTIVE: The aircraft landing system at the U.S. bases in Antarctica must be replaced in the next few years. GPS is the primary candidate system for use in this remote site. There are several special features about the local environment in polar latitudes that must be studied and validated before flight safety can be assured. Dr. Clynch offers advise to the Antarctic Landing Systems committee as a member and their scientific advisor.

SUMMARY: The technical capability of a differential GPS system to meet the landing requirements in Antarctic has been demonstrated in an ongoing effort over five years. During 2001 the effort focused on following the FAA specification development process for the Local Area Augmentation System (LAAS). During this year the FAA LAAS specification can to closure, at least on a first edition. Test systems are in place in the U.S. and vendors are taking orders. The efforts this year also included investigations of the effects of radio frequency interference on GPS and GPS landing systems.

PROJECT SUMMARIES

GPS FIELD TEST QUICK LOOK SOFTWARE UPGRADE
James R. Clynch, Research Professor
Department of Oceanography
Sponsor: Naval Surface Warfare Center - Dahlgren Division

OBJECTIVE: To update GPS data quality software to run with newer GPS formats.

SUMMARY: NSWC and NPS have cooperated on GPS experiments and data analysis for several years. Some of their routinely used software originated at NPS. This software does not function with the implementation of new formats by some of the GPS manufacturers. New versions of the software now functions with the hardware NSWC uses in field experiments.

CENTRAL CALIFORNIA HYDROGRAPHIC SURVEYS
Curtis A. Collins, Professor
Department of Oceanography
Sponsor: San Jose State University Foundation and Scripps Institute of Oceanography

OBJECTIVE: The objective of this project are to extend the hydrographic data base off the U.S. West Coast for the Naval Oceanographic Office and to improve the understanding of the California Current and its associated upwelling ecosystem.

SUMMARY: Hydrographic surveys of Central California waters were conducted in May and December, 2001 by the R/V *New Horizon* and the R/V *Point Sur*, respectively. Surveys were based upon the California Cooperative Fisheries Investigations station pattern and ranged from Point Reyes to Point Sur and offshore to a distance of about 160 km. Three 25-hr time series stations were also sampled, two in the Gulf of the Farallons and one in Monterey Bay. Biological and chemical sampling was included along the hydrographic line that extends offshore from Moss Landing (Line 67). December data collection efforts were limited by poor weather conditions and were not as extensive as those in May.

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DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Hydrographic Data, Ocean Currents, El Niño

OCEAN CURRENTS AND SEDIMENT TRAP MEASUREMENTS
Curtis A. Collins, Professor
Department of Oceanography
Sponsor: Monterey Bay Aquarium Research Institute

OBJECTIVE: The objective of this program is to measure the deep currents and vertical sediment fluxes below the relatively well-sampled surface ocean waters offshore of Monterey Bay.

SUMMARY: Ocean current and sediment trap measurements were continued at site S2 (36-40N, 122-22W) in 2001. The intermediate mooring was recovered and replaced on January 25, 2001 and August 16, 2001. Current and sediment trap measurements were made at depths of 300 and 1200 m.

PUBLICATIONS:

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THESIS DIRECTED:

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DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Ocean Currents, Sediment Flux

NONHYDROSTATIC MODELING OF WEST FLORIDA SHELF FLOW AND TRACERS
Roland W. Garwood, Jr., Professor
Ramsey Harcourt, Research Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objective is to calculate nonstationary three-dimensional solutions for the turbulent nonhydrostatic flow regime on the West Florida shelf using Large-Eddy Simulation. These solutions will be used to help explain the three-dimensional optical properties of the water column by understanding the behavior of tracers and drifters deployed during field experiments.

SUMMARY: In collaboration with Kent Fanning and John Walsh of the University of South Florida the OPBL Laboratory of the Naval Postgraduate School is conducting numerical solutions for the turbulent nonhydrostatic flow regime on the West Florida shelf using Large-Eddy Simulation. These solutions are for times and locations appropriate to explain the optical properties of the water column by understanding the behavior of tracers and drifters deployed during field experiments with AUVs (autonomous underwater vehicles). Animated GIFS of the turbulent boundary layer on the West Florida shelf, which have been produced with the assistance of NRC Postdoctoral Associate, Pascale Lherminier, are used to display the three-dimensional unsteady evolution of the turbulent fluxes and turbulent kinetic energy attributable to the combined forcing by the winds and the geostrophic current.

PUBLICATIONS:

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CONFERENCE PRESENTATION:

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DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Sensors, Modeling and Simulation, Other (Oceanography)

KEYWORDS: Air-Sea Interactions, Tracers, Lagrangian Drifters

POLAR SEA CONVECTIVE INSTABILITIES
Roland W. Garwood, Jr., Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The major scientific objective of this five-year study has been to understand the convective response of the coupled ocean mixed layer-ice system to the passage of atmospheric storms. The connection between the earth's atmosphere and its deep oceans begins with the cooling and sinking of seawater in the polar seas. This convection process is the 'engine' of the 'conveyer belt' of global-scale oceanic circulation for renewal and replacement of the large volume of deep water that spreads across the earth's connected ocean basins. This project has sought to explain the previously poorly understood process of oceanic deep convection that occurs very rapidly (order of hours to days) and on a very small (order of a few kilometers) scale in comparison with the space and time scales of the conveyor belt (order of tens of thousands of kilometers and hundreds of years, respectively).

SUMMARY: The most significant results include the theoretical prediction and numerical verification of a new class of convective instabilities. These instabilities, which arise due to the nonlinear relationship of seawater density upon salinity, temperature, and pressure, produce vertical convection in the polar oceans that physically may resemble vertical convection by cumulus clouds in the tropical atmosphere. As for the

cumulus convection in the atmosphere, this oceanic convection may produce some of the largest vertical velocities in the world's oceans.

These results will guide future work on how to better include the effects of oceanic deep convection in coupled oceanic-atmospheric climate and global change predictions. The results will also suggest where, when and how to design field experiments to monitor and detect deep convection and signs of climate change. Tools that enabled success in this research include: (1) Large-Eddy Simulation (LES) on high-performance computers, which is the numerical modeling of the full equations of motion without the limiting assumptions usually applied in oceanic circulation modeling; (2) Verification of LES computer predictions with actual oceanic observations from Lagrangian drifters.

Major findings are:

1. The comparison between one-dimensional mixed-layer and three-dimensional LES models is leading to improved parameterization of entrainment and convection for eventual inclusion in basin-scale OGCMs.

2. LES results for conditional instabilities are confirmation and improvements of our understanding of the probable nature of parcel and layer instabilities in the ocean.

3. Large-scale horizontal gradients in temperature and salinity generate mesoscale cyclones and anti-cyclones that modify the deep convection caused by local surface cooling.

4. Thermobaricity has been found to generate conditional instabilities of two kinds: i) parcel, and ii) layer. A third phenomenon, 'thermobaric stability' has been identified that can enable lenses and filaments of T-S density-compensated water to remain stable and unmixed as it is advected laterally and from the polar sea basins and onto the shelf.

5. Biases in Motion of Drifters in Convection. Earlier Large-Eddy Simulations (LES) showed that isobaric floats would tend to accumulate in convergence zones. Since these convergence zones are associated with local mean vertical velocity, the isobaric drifters were predicted to experience a mean vertical velocity, even if there were no vertical flow horizontally averaged at that depth. Modeling of isobaric floats by LES for the winter of 1994 in the Greenland Sea and of 1996 in the Labrador Sea show that the bias in drifter-observed vertical velocity measurements bears also on the estimation of variances and vertical fluxes derived from drifter-observed temperature and salinity. Quantification of this bias is possible at least in the lower part of the mixed layer, provided that the horizontal divergence field is known.

6. Ice Model Added to LES. The study of 1996 float data in the Greenland Sea and of ANZFLUX hydrographic profiles in the Weddell Sea led us to add a thermodynamic sea ice layer on top of the LES. All the second order non-linearities of the seawater equation of state (as thermobaricity and cabbelling) were included in order to better understand the relative effect of each. It is seen that cabbelling delays the growth of penetrative thermobaric plumes and favors the formation of an intermediate layer often observed in the Wedell Sea, but still unexplained.

7. Thermobaricity and Maintenance of Sensible Heat Polynyas. A critical mixed layer depth for free-convection under polynyas was predicted. This is potentially very significant for deep water formation beneath sensible heat polynyas such as the Wedell Polynya as well as near-freezing open water in the Greenland Sea and other marginal ice zones Wherever warmer and saltier intermediate water underlies polar sea surface mixed layers, entrainment of the deeper water into the surface mixed layer convects heat upward that may melt ice and/or inhibit further freezing. Forced convection by wind stirring may lead to such melting, especially if the mixed layer is shallow and free convection from surface cooling is not large. For deeper mixed layers, however, the turbulent kinetic energy (TKE) budget for a mixed layer of depth h shows that the TKE that leads to deep free convection and entrainment is most readily generated by strong upward surface buoyancy flux associated free convection induced by surface cooling. The classical TKE model having a linear equation of state predicts that the upward entrainment heat flux into the bottom of the such deep mixed layers generally will be less than the upward surface heat flux into the atmosphere and/or ice. Hence, surface cooling usually has been expected to predominate over entrainment warming, with the net result of freezing or mixed-layer cooling until freezing does occur. In a nonclassical free convection model demonstrated for the first time, the TKE budget is corrected to include thermobaricity, the increase in the thermal expansion of seawater with increased pressure. This correction to buoyancy and buoyancy flux from a proper equation of state shows clearly the relationship between depth of mixing and the increase in entrainment due to thermobaricity. In particular, a critical depth (HCR) of mixing is predicted for which any

surface cooling will lead to melting of ice and subsequent net warming of the surface layer. Mixed layers deeper than this critical depth (h> HCR) will melt ice and maintain polynyas regardless of the intensity of surface cooling. Such super-critical mixed layers may be initiated either by wind-aided forced convection, or by advection. Near-critical cases including the Weddell polynya will be examined in future research.

PUBLICATIONS:

Lherminier, P., R.R. Harcourt, R.W. Garwood, Jr. and J.-C. Gascard, Interpretation of mean vertical velocities measured by isobaric floats during deep convection events, *Journal of Marine Systems*, 29, 221-237, 2001.

Harcourt, R.R., E.L. Steffan, E.L., Garwood, R.W., Jr. and D'Asaro, E.A., Fully Lagrangian floats in Labrador sea deep convection: comparison of numerical and experimental results, *Journal of Physical Oceanography*, in press, 2001.

PRESENTATION:

Garwood, R.W., Jr., Critical mixed layer depth for maintaining convective polynyas, International Polynyas Symposium, Quebec City, Canada, 9-13 September 2001.

DoD KEY TECHNOLOGY AREA: Battlespace Environments, Environmental Quality, Sensors, Modeling and Simulation, Other (Oceanography)

KEYWORDS: Air-Sea Interactions, Ocean Convection

THERMOBARICITY: A COLLABORATIVE WEBSITE
Arlene Guest, Senior Lecturer
Department of Oceanography
Sponsor: McPhee Research Company

OBJECTIVE: The goal of this project is to expedite the sharing and exchange of scientific about thermobaricity and to facilitate the planning and design of observation and modeling studies of thermobaricity in a collaborative web environment.

DoD KEY TECHNOLOGY AREAS: Environmental Quality

KEYWORDS: Thermobaricity, Collaborative, WEB, Environments

DATA ENHANCED MODELING OF SEA AND SWELL ON THE CONTINENTAL SHELF
Thomas H. C. Herbers, Associate Professor
William C. O'Reilly, Research Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: To develop and test improved wave propagation and data assimilation methods that are compatible with the coastal wave prediction model SWAN and applicable to a wide range of geographic settings.

SUMMARY: Data assimilation methods are under development for the coastal wave prediction model SWAN. Currently SWAN and similar regional wave prediction models are nested within the global wave prediction model WAM. A drawback of this approach is that initialization errors (e.g., errors in WAM predictions owing to uncertainties in the wind field and inaccuracies in the propagation of waves over large distances) can seriously degrade the coastal model predictions. In this project new methods are

implemented to enhance the quality of coastal wave predictions through the assimilation of in-situ (e.g. directional wave buoys) and remotely sensed (e.g., airborne and satellite radar systems) wave data collected at the offshore boundaries or within the model domain. This project is an ongoing collaboration with scientists from NRL-SSC.

PRESENTATIONS:

Wingeart, K., W.C. O'Reilly, T.H.C. Herbers, P.A. Wittmann, R.E. Jensen and H.L. Tolman, Validation of operational global wave prediction models with spectral buoy data, *Proceedings Fourth International Symposium on Ocean Wave Measurement and Analysis*, American Society of Civil Engineers, 2001, in press.

THESIS DIRECTED:

Wingeart, K., "Validation of Operational Global Wave Prediction Models with Spectral Buoy Data," Masters Thesis, Naval Postgraduate School, December 2001.

DoD KEY TECHNOLOGY AREA: Environmental Quality, Battlespace Environments

KEYWORDS: Wave and Surf Forecasts, Data Assimilation

IMPROVED PARAMETERIZATIONS OF TRIAD AND QUARTET INTERACTIONS IN SPECTRAL WIND-WAVE MODELS
Thomas H. C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main objective of this project is to improve the representation of nonlinear wave-wave interactions in operational wave prediction models.

SUMMARY: It is well known that nonlinear wave-wave interactions are poorly represented in current operational wave prediction models (e.g., WAM, SWAN). In this project a team of scientists from the Naval Postgraduate School, the Army Corps of Engineers, David Taylor Model Basin, and Alkyon Hydraulic Consultancy and Research, are evaluating the shortcomings of existing models and developing and testing new approximations. A numerically efficient technique for computing the energy exchanges between four wave components in quartet interaction was validated through comparisons with exact numerical calculations.

DoD KEY TECHNOLOGY AREA: Environmental Quality, Battlespace Environments

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Continental Shelf, Beach

NEARSHORE CANYON EXPERIMENT (NCEX)
Thomas H. C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this research is to understand the effect of complex continental-shelf bathymetry on surface gravity waves and on the breaking-wave-driven circulation onshore of the irregular bathymetry.

SUMMARY: Abrupt shelf bathymetry can cause dramatic alongshore variations in waves, resulting in beaches with large waves located only a few hundred meters away from beaches with small waves. These along-coast changes in wave height and direction can force complicated circulation patterns, including

alongshore flows that reverse direction across the surf zone and along the shoreline, and strong offshore-directed rip currents that may be an important mechanism for transport of water, sediment, and pollution between the surf zone and inner shelf. Models will be tested with observations of waves and currents made on the southern California coast near two steep submarine canyons. Model initial conditions (incident waves) will be acquired with a directional buoy located offshore of the canyons. The effect of the canyons on waves and wave-driven circulation will be measured with directional buoys near the canyons, and with pressure-gage and current-meter arrays deployed onshore of the canyons in 10- and 2.5-m water depths. Additional specialized arrays will be deployed to investigate wave reflection and scattering from the steep canyon walls, and cross-shore changes in surf zone circulation. Drifters will be used to estimate the location, flow speed, and offshore extent of rip currents. This project is a collaborative effort with Woods Hole Oceanographic Institution (Dr. Steve Elgar) and Scripps Institution of Oceanography (Dr. Robert T. Guza).

PUBLICATIONS:

Elgar, S., R.T. Guza, W.C. O'Reilly, B. Raubenheimer and T.H.C. Herbers, Wave energy and direction observed near a pier, *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 127(1), 2-6, 2001.

DoD KEY TECHNOLOGY AREA: Environmental Quality, Battlespace Environments

KEYWORDS: Ocean Surface Waves, Surf Zone, Nearshore Processes

SURFACE GRAVITY WAVES ON THE CONTINENTAL SHELF AND BEACH
Thomas H. C. Herbers, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The main objective of this project is to predict accurately the evolution of surface waves from deep water across the continental shelf to the beach.

SUMMARY: This project is focused on the effects of nonlinear wave-wave interactions and wave breaking on the evolution of wind-wave spectra across the inner continental shelf and beach. Analysis of detailed wave shoaling measurements collected during the DUCK94 and SandyDuck (1997) experiments demonstrates the important role of nonlinear triad wave-wave interactions in the surf zone energy balance. Analysis of array measurements in shallow water shows significant deviations from the linear dispersion relation for surface gravity waves. A new nonlinear dispersion relation was derived and shown to be in good agreement with the field measurements.

PUBLICATIONS:

Lentz, S., M. Carr and T.H.C. Herbers, Barotropic tides on the North Carolina shelf, *Journal of Physical Oceanography*, 31(7), 1843-1859, 2001.

Noyes, T.J., R.T. Guza, S. Elgar and T.H.C. Herbers, Comparison of methods for estimating nearshore shear wave variance, *Journal of Atmospheric Oceanic Technology*, 19(1), 136-143, 2002.

Herbers, T.H.C., S. Elgar, N.A. Sarap and R.T. Guza, Nonlinear dispersion of surface gravity waves in shallow water, *Journal of Physical Oceanography*, 2002, in press.

Sheremet, A., R.T. Guza, S. Elgar and T.H.C. Herbers, Observations of nearshore infragravity waves. Part 1: Seaward and shoreward propagating components, *Journal of Geophysical Research*, 2002, in press.

Herbers, T.H.C., M. Orzech, S. Elgar and R.T. Guza, Shoaling transformation of wave frequency-directional spectra, *Journal of Geophysical Research*, 2002, submitted.

PRESENTATIONS:

Sheremet, A., R.T. Guza, S. Elgar and T.H.C. Herbers, "Estimating infragravity wave properties from pressure-current meter array observations," *Proceedings of the Twenty Seventh International Conference on Coastal Engineering,* ed. Billy L. Edge, American Society of Civil Engineers, pp. 1476-1489, Sydney, Australia, 2001.

Lippmann, T.C., T.H.C. Herbers and E.B. Thornton, "Observations of infragravity waves in the nearshore," *Proceedings of the Fourth Coastal Dynamics Conference*, ed. E.B. Thornton, American Society of Civil Engineers, pp. 55-61, Lund, Sweden, 2001.

THESES DIRECTED:

Balolong, M.O., "Validation of a Stochastic Boussinesq Model for Wave Spectra Transformation in the Surf Zone," Masters Thesis, Naval Postgraduate School, June 2001.

Ruth, D., "A Nonlinear Wave Shoaling Model for Alongshore Varying Bathymetry," Masters Thesis, Naval Postgraduate School, September 2001.

DoD KEY TECHNOLOGY AREA: Environmental Quality, Battlespace Environments

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Continental Shelf

WAVE EVOLUTION ON THE CONTINENTAL SHELF
Thomas H. C. Herbers, Associate Professor
Department of Oceanography
Sponsors: Office of Naval Research and Naval Postgraduate School

OBJECTIVE: The main objective of this project is to evaluate the energy balance of wind-generated waves in shallow water.

SUMMARY: Six surface-following directional wave buoys and a coherent array of pressure sensors were deployed on the North Carolina continental shelf as part of the ONR SHoaling Waves EXperiment (SHOWEX) to investigate the transformation of wind waves and swell across a continental shelf. High-quality data was collected through a wide range of conditions including Hurricanes Floyd, Gert, and Irene with maximum wave heights in excess of 10 m. Detailed bottom information was collected during three cruises including sediment samples, sidescan surveys of small-scale bottom roughness and high resolution bathymetry. Analysis of the SHOWEX observations by Ph.D. student Fabrice Ardhuin using a new numerical model for wave evolution across the continental shelf has demonstrated the important role of seabed ripples in the attenuation of swell. The measurements will also be used to verify theoretical predictions of nonlinear spectral energy transfers and estimate wave energy losses resulting from whitecaps.

PUBLICATIONS:

Ardhuin, F., T.H.C. Herbers and W.C. O'Reilly, A hybrid Eulerian-Lagrangian model for spectral wave evolution with application to bottom friction on the continental shelf, *Journal of Physical Oceanography,* 31(6), 1498-1516, 2001.

Ardhuin, F. and T.H.C. Herbers, Bragg scattering of random surface gravity waves by irregular sea bed topography, *Journal of Fluid Mechanics*, 451, 1-33, 2002.

Ardhuin, F., T.G. Drake and T.H.C. Herbers, Observations of wave-generated vortex ripples on the North Carolina continental shelf, *Journal of Geophysical Research*, 2002, in press.

PRESENTATIONS:

Ardhuin, F., W.C. O'Reilly, T.H.C. Herbers, C.V. Tinder and P. Jessen, "Observations and modeling of swell evolution across a wide continental shelf," Proceedings Fourth International Symposium on Ocean Wave Measurement and Analysis, American Society of Civil Engineers, in press.

Ardhuin, F., Herbers, T.H.C., O'Reilly, W.C. and Jessen, P.F., "Validation of a spectral energy balance model for swell on the continental shelf," Eos Transactions AGU, 82(47), Fall Meeting Supplemental, Abstract OS31B-0414, 2001

THESIS DIRECTED:

Ardhuin, F., "Swell Across the Continental Shelf," Ph.D. Dissertation, Naval Postgraduate School, September 2001.

DoD KEY TECHNOLOGY AREA: Environmental Quality, Battlespace Environments

KEYWORDS: Ocean Surface Waves, Nonlinear Interactions, Wave Breaking, Bottom Friction, Continental Shelf

COUPLED BIOPHYSICAL MODELING OF THE ARCTIC MARINE RESPONSE TO GLOBAL CHANGE

Wieslaw Maslowski, Research Associate Professor
Roland W. Garwood, Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: To provide a comprehensive understanding of shelf-basin exchange processes, biogeochemical cycles, and their role in the large-scale interannual variability of the Arctic Ocean system and to integrate this knowledge into predictive models of the consequences of global change.

SUMMARY: Some of the most important results from the earlier 18-km and 30-level model include: (i) simulation of the recent (1979-98) large-scale changes in sea ice and the upper ocean circulation in response to atmospheric conditions in qualitative agreement with observations, (ii) finding that the large scale circulation in the Arctic Ocean occurs via narrow (~100km), topographically controlled flows, which require a grid spacing of order 10 km to be adequately represented, (iii) determination of preferred pathways of fresh water transport from the shelves, accumulation in the deep basins and export out of the Arctic Ocean, and their inter-annual to decadal variability.

The ongoing integration of the new 9-km model with 1979-2001 atmospheric forcing will continue during the CY02. Comparisons of the large scale currents and eddy energetics between the two models will be emphasized. In addition to physical improvements of ocean and ice processes, the importance of model resolution in representing details of local dynamics and the main circulation features will be determined.

PUBLICATIONS:

Maslowski, W., D.C. Marble, W. Walczowski and A.J. Semtner, On large-scale shifts in the Arctic Ocean and sea ice conditions during 1979-98, *Annals of Glaciology*, 23, pp. 545-550, 2001.

Preller, R.H., W. Maslowski, D. Stark, P. Posey and T.T.C. Pham, Navy sea ice prediction systems, *The Oceanographic Society*, 2001, in press.

Walczowski, W., W. Maslowski, D.C. Marble and A.J. Semtner, Ocean circulation and shelf-basin exchanges in the Canada Basin from a high resolution model, *AMS Polar Meteorology and Oceanography Conference Extended Abstracts*, 2001.

Walczowski, W., and W. Maslowski, Shelf-basin circulation and exchanges in the Western Arctic high resolution model results, draft manuscript, 2001.

PRESENTATIONS:

Maslowski, W., W. Walczowski and D.C. Marble, "Towards realistic modeling of physical processes and large scale circulation in the Arctic Ocean," Western Arctic Shelf Basin Interaction PI Meeting, Albuquerque, NM, 8-9 February 2001.

Maslowski, W., W. Walczowski and D.C. Marble, "Environmental conditions in the Western Arctic during 1979-1981 - model results," ARCSS-OAII All Hands Meeting, Salt Lake City, UT, 14-16 November 2001.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Ocean Modeling, Biophysical Environment, Eddies, Shelf-Basin Exchanges

INTERANNUAL VARIABILITY OF BIOPHYSICAL LINKAGES BETWEEN THE BASIN AND SHELF IN THE BERING SEA
Wieslaw Maslowski, Research Associate Professor
Department of Oceanography
Sponsor: National Atmospheric and Oceanic Administration

OBJECTIVE: To identify interannual and interdecadal variations in the circulatory and mixing pathways by which nutrients are communicated from the deep ocean to the adjacent shelves in the Bering Sea and western Gulf of Alaska using .an eddy-permitting ice-ocean model of the Pan-Arctic region.

SUMMARY: The coupled ice-ocean model configured at 9-km and 45-level grid was developed and integrated for 50 years. The model domain includes the North Pacific (to ~30oN), the Arctic Ocean, and the North Atlantic (to ~45oN). Model output realistically predicts the net northward transport through Bering Straits and its seasonal and interannual variability. To our knowledge, this is the first model to show such a skill, which is critical for proper modeling of local processes and large-scale circulation in the Bering Sea and the Gulf of Alaska. In the past, global ocean models either did not include the region to the north of Bering Strait or prescribed a fixed northward flow based on observations, due to lack of resolution necessary to properly represent ocean circulation in the region.
 Numerical tracers were introduced to allow tracking of Pacific Water pathways and mixing across the Aleutian Archipelago and along the Bering slope, where high nutrient concentrations and increased marine life activities were observed.
 The ongoing production integration with 1979-2001 atmospheric forcing will continue during the CY02. Analyses of model results will emphasize physical processes and their role in interannual variability of water mass properties and nutrients in the study region.

PUBLICATIONS:

McClean, J. L., W. Maslowski and M.E. Maltrud, Towards a coupled environmental prediction system, computational science, ICCS 2001, eds: Alexandrov, Dongorra, Juliano, Renner and Tan, *Lecture Notes in Computer Science 2073*, Springer-Verlag, pp. 1098-1107, 2001.

PRESENTATIONS:

Maslowski, W., Advances in modeling the Arctic Ocean, An invited seminar in the NSF-Sponsored Arctic Visiting Speakers' Series, Oregon State University, Corvallis, OR, 23-25 January 2001.

Maslowski, W., Towards eddy-resolving ocean/ice modeling of the pan- Arctic region, An invited seminar at the Artic Region Supercomputing Center Technology Panel, Fairbanks, AK, 12-16 February 2001.

Maslowski, W. and J. McClean, Advanced modeling of the Navy operational environments, DoD High Performance Computer Modernization Program User Group Meeting, Biloxi, MS, 18-21 June 2001.

Maslowski, W., 1/12-degree pan-Arctic coupled ice-ocean model - spin up results, Climate Change Prediction Program Meeting, San Diego, CA, 1-3 October 2001.

McClean, J.L, W. Maslowski and M. Maltrud, Towards a coupled environmental prediction system, International Conference on Computational Science, San Francisco, CA, May 2001.

McClean, J.L, W, Maslowski and M. Maltrud, Advanced modeling of the navy operational environments, Part II, DoD HPCMO Users Group Conference, Biloxi, MS, June, 2001.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Ocean Modeling, Biophysical Environment, Eddies, Shelf-Basin Exchanges

MODELING THE LONG-TERM TURBULENT CIRCULATION OF ARCTIC OCEAN AND ITS SEA ICE

Wieslaw Maslowski, Research Associate Professor
Albert J. Semtner, Professor
Yuxia Zhang, Research Assistant Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The main goal of this investigation involved simulation of the long-term circulation of the ice-covered Arctic Ocean driven by realistic atmospheric forcing using advanced parallel computers.

SUMMARY: The most important achievements from the 18-km and 30-level model included: (i) simulation of the recent (1979-98) large-scale changes in sea ice and the ocean circulation in response to atmospheric conditions in qualitative agreement with observations, (ii) finding that the large scale circulation in the Arctic Ocean occurs via narrow (~100km), topographically controlled flows, which require a grid spacing of order 10 km to be adequately represented, (iii) determination of preferred pathways of fresh water transport from the shelves, accumulation in the deep basins and export out of the Arctic Ocean, and their inter-annual to decadal variability, (iv) improved understanding of pathways and distribution of different water masses due to the incorporation of numerical tracers to track them throughout the model simulation.

PUBLICATIONS:

Marble, D.C., W. Maslowski, W. Walczowski, U. Schauer and A.J. Semtner, Simulated annual mass, heat and salt transport through the Barents Sea from an eddy-permitting Pan-Arctic coupled ice-ocean model, *Journal of Geophysical Research*, conditionally accepted, 2001.

Steele, M., W. Ermold, S. Hakkinen, D, Holland, G. Holloway, M. Karcher, F. Kauker, W.Maslowski, N. Steiner and J. Zhang, Adrift in the Beaufort Gyre: A model intercomparison, *Geophysical Research Letters*, 28, pp. 2935-2938, 2001.

Weatherly, J.W. and Y. Zhang, The response of the polar regions to increased CO2 in a global climate model with elastic-viscous-plastic sea ice, *Journal of Climate*, 14, 268-283, 2001.

Zhang, Y. and E.C. Hunke, Recent Arctic change simulated with a coupled ice-ocean model, *Journal of Geophysical Research*, 106, 4369-4390, 2001.

Zhang, Y. and A.J. Semtner, The Antarctic circumpolar wave in a high-resolution ice-ocean simulation, *Annals of Glaciology*, 2001, in press.

PRESENTATIONS:

Maslowski, W., W. Walczowski and D.C. Marble, The circulation of the Baltic Sea and its communication with the North Atlantic - a large scale and high resolution modeling approach, The Third Study Conference on BALTEX, Mariehamn, Finland, 2-6 July 2001.

Semtner, A.J. and Y. Zhang, Polar ocean circulation, variability, and anthropogenic change, as depicted in high-resolution coupled models, Gordon Research Conference on Polar Marine Science, Ventura, CA, 12-16 March 2001.

THESIS DIRECTED:

Marble, D.C, "Simulated Annual and Seasonal Arctic Ocean and Sea-ice Variability from a High Resolution Coupled Ice-ocean Model," Ph.D. Dissertation, Naval Postgraduate School, September 2001.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Ocean Modeling, Climate Change, Ice-Ocean Interactions, Decadal Variability

COMPARISONS OF THE LANL POP MODEL AND WOCE OBSERVATIONS
Julie L. McClean, Research Assistant Professor
Albert J. Semtner, Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: To evaluate the global 0.28°, 20-level Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP) model with observational data collected during the World Ocean Circulation Experiment (WOCE).

SUMMARY: Two new POP simulations were run and analyzed to correct deficiencies identified by earlier comparisons of the 0.28°, 20-level POP model with the WOCE data. Eulerian and Lagrangian velocity statistics were calculated from North Atlantic surface drifting buoys and a new 0.1°, 40-level North Atlantic configuration of POP. The high-resolution model produced a very realistic ocean state for 1993-1997 in terms of mean flows, energy levels, and intrinsic scales. A two-decade repeat-XBT line collected between Java and Australia was compared with co-located output from a 1/3°, 32-level global POP simulation. The seasonal to interannual variability found in the data was well reproduced by the model. The larger space-time context of the model was then used to understand the causes of this variability.

PUBLICATIONS:

McClean, J.L., W. Maslowski and M.E. Maltrud, Towards a coupled environmental prediction system, *Computational Science - ICCS 2001*, eds: Alexandrov, Dongorra, Juliano, Renner, and Tan, Lecture Notes in Computer Science 2073, Springer-Verlag, pp 1098-1107, 2001.

McClean, J.L., P.-M. Poulain, J.W. Pelton and M. Maltrud, Eulerian and Lagrangian statistics from surface drifters and two POP models in the North Atlantic. *Journal of Physical Oceanography*, 2001, accepted.

PRESENTATIONS:

McClean, J.L. and M. Maltrud, Mass and heat transports in the global 0.28-degree POP model. South Atlantic Model-Data Meeting, Los Alamos National Laboratory, Los Alamos, NM, March 2001.

McClean, J.L., High resolution ocean modeling for synoptic forecasting and short-term climate studies, Invited Seminar, Romberg-Tiburon Center, San Francisco State University, CA, April 2001.

McClean, J.L., P.-M. Poulain, J.W. Pelton, M. Maltrud and D. Ivanova, Eulerian and Lagrangian statistics from surface drifters and two POP models in the North Atlantic, Western Boundary Current Virtual Poster Session, http://www.gso.uri.edu/wbc/Mcclean, May 2001.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Ocean Circulation, Model Validation, Model/Data Synthesis

EVALUATIONS OF THE POP MODEL FOR NAVY FORECASTING USE
Julie L. McClean, Research Assistant Professor
Robin T. Tokmakian, Research Assistant Professor
Albert J. Semtner, Professor
Ching-Sang Chiu, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: To continue high-resolution simulations and analyses of the Los Alamos National Laboratory (LANL) Parallel Ocean Program (POP) model for global Navy forecasting needs. This project is ongoing.

SUMMARY: The spin-up phase of a 0.1°, 40-level global configuration of the POP model continued along with assessments of its realism. These assessments were made by comparing appropriate data sets with the model solution. Sensitivity studies were conducted in basins where the model solution was found to be unrealistic to identify the causes of these behaviors and correct them. In particular, mixed layer dynamics, key basin overflows, and western boundary current separations and flows were examined.

PUBLICATIONS:

McClean, J.L., W. Maslowski and M.E. Maltrud, Towards a coupled environmental prediction system, *Computational Science - ICCS 2001*, eds: Alexandrov, Dongorra, Juliano, Renner, and Tan, Lecture Notes in Computer Science 2073, Springer-Verlag, pp. 1098-1107, 2001.

McClean, J.L., P.-M. Poulain, J.W. Pelton and M. Maltrud, Eulerian and Lagrangian statistics from surface drifters and a high resolution POP simulation in the North Atlantic. *Journal of Physical Oceanography*, 2001, Accepted.

PRESENTATIONS:

McClean, J.L., Towards the use of POP in a global coupled Navy prediction system, SPAWAR/ONR Joint Internal Program Review, Naval Research Laboratory, Monterey, CA, February 2001.

McClean, J.L., P.M. Poulain, J.W. Pelton, M. Maltrud and D. Ivanova, Eulerian and Lagrangian statistics from surface drifters and two POP models in the North Atlantic, Western Boundary Current Virtual Poster Session, http://www.gso.uri.edu/wbc/Mcclean, May 2001.

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McClean, J.L., W. Maslowski and M. Maltrud, Advanced modeling of the Navy operational environments, Part II, DoD HPCMO Users Group Conference, Biloxi, MS, June 2001.

McClean, J.L., Towards a coupled environmental prediction system, invited seminar, Navy Oceanographic Office, Stennis Space Center, MS, June 2001.

McClean, J.L. and M. Maltrud, High resolution POP, Kuroshio Extension System Study (KESS) Planning Meeting, University of Rhode Island, RI, November 2001.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Ocean Circulation, Model Validation, Model/Data Synthesis

AN INNOVATIVE COASTAL-OCEAN OBSERVING NETWORK
Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objective of this project is to show that real-time data from HF radars and acoustic tomography can improve the performance of coastal circulation and biological productivity models.

SUMMARY: A concept demonstration is underway by a consortium of government, academic, and industrial partners to show how a diverse suite of modern, innovative ocean instrumentation can be successfully integrated into a functional, real-time ocean observation network. The plan calls for both creative application of well established observational techniques and the development of new instrumentation and algorithms, which will be utilized in the network for the very first time. Moored, single-point time series observations, remotely-sensed data, ocean acoustic tomography, and two-dimensional vector fields obtained from HF radars are being integrated into a cohesive picture of the coastal environment via a nested, high resolution numerical model. The sensor data and model output are being made available via Internet web pages for immediate application by coastal managers, defense analysts, emergency response teams, and commercial and recreational use.

PUBLICATIONS:

Shulman, I., C.-R. Wu, J.K. Lewis, J.D. Paduan, L.K. Rosenfeld, J.D. Kindle, S.R. Ramp and C.A. Collins, High resolution modeling and data assimilation in the Monterey Bay area. *Continental Shelf Research*, in press, 2001.

Ramp, S.R., D.E. Barrick, L.A. Pederson, J.C. Lee, J.D. Paduan and I. Shulman, Recent advances in coastal HF radars with potential application to the Asian marginal seas. *Proceedings of the Eleventh PAMS/JECSS Workshop*, Cheju, Korea, 11-13 April 2001.

Shulman, I., J.D. Paduan, C.-R. Wu, J.K. Lewis, L.K. Rosenfeld and S.R. Ramp, High frequency radar data assimilation in the Monterey Bay. *Proceedings of the Seventh International Estuarine and Coastal Modeling Conference*, St. Petersburg, FL, November 2001.

PRESENTATIONS:

Cook, M.S., J.D. Paduan, I. Shulman, D.M. Fernandez and C. Whelan, Statistics and data assimilation results from long-term HF radar-derived surface currents around Monterey Bay. Eastern Pacific Ocean Conference, Stanford Sierra Camp, Fallen Leaf Lake, CA, 23-26 September 2001.

Paduan, J.D. Application of HF radar in coastal oceanography. Introduction to HF radar workshop, Oceanology International, Miami FL, 3-5 April 2001.

Paduan, J.D., Cook, M.S., I. Shulman, D.M. Fernandez and C. Whelan, Statistics and data assimilation results from long-term HF radar-derived surface currents around Monterey Bay. First Radiowave Oceanography Workshop, Timberline Lodge, Mt. Hood, OR, 9-12 April 2001.

Paduan, J.D., Cook, M.S., D.M. Fernandez and C. Whelan, Statistics and data assimilation results from long-term HF radar-derived surface currents around Monterey Bay. Oceanology International, Miami FL, 3-5 April 2001.

Rosenfeld, L.K., Monterey Bay's innovative coastal-ocean observing network, Interactive Symposium on Information Exchange in Coastal Oceanography, Meteorology, and Hydrology; Eighty First American Meteorological Society Annual Meeting, 14-18 January 2001.

Rosenfeld, L.K., R. Durazo, I. Shulman, J.D. Paduan, D. Blencoe, S. Ramp and C. Collins, Comparison between modeled and measured velocity and temperature fields from an Innovative Coastal-Ocean Observing Network (ICON). Eastern Pacific Ocean Conference, Stanford Sierra Camp, Fallen Leaf Lake, CA, 23-26 September 2001.

THESIS DIRECTED:

Blencoe, D.G., "Impact of High Resolution Wind Fields on Coastal Ocean Models." Masters Thesis, Naval Postgraduate School, September 2001.

OTHER:

Rosenfeld, L.K. and J.D. Paduan, "An Innovative Coastal-Ocean Observing Network (ICON)." Invited presentation, FNMOC Open House, Monterey, CA, 21 April 2001.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Modeling and Simulation

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction

DIURNAL TO SEASONAL VARIABILITY OF SURFACE OCEAN CURRENTS FROM HIGH FREQUENCY RADAR
Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsors: National Science Foundation and Naval Postgraduate School

OBJECTIVE: The goals of this project are to describe the wind and tide forcing of the upper ocean currents around Monterey Bay and to develop optimized HF radar current algorithms.

SUMMARY: This research is drawing on data from a unique array of five HF radar systems around Monterey Bay: three CODAR-SeaSonde direction-finding systems and two multi-frequency phased array systems. Focus is on the 2-D surface currents and how they vary, both seasonally and daily, compared with measured winds and satellite AVHRR images. Data from the multi-frequency radar sites is being used to measure near-surface shear, which is difficult to do with in situ instrumentation. In addition, data from these systems, as well as simulations, is being used to examine the sensitivity of radar algorithms to varying current and wave conditions.

PUBLICATIONS:

Fernandez, D.M., L.A. Meadows, J.F. Vesecky, C.C. Teague, J.D. Paduan and P. Hansen, Surface current measurements by HF radar in fresh water lakes. *Journal of Oceanic Engineering*, 25, 458-471, 2001.

Fernandez, D. M., J.F. Vesecky, D.E. Barrick, C.C. Teague, M.M. Plume and C. Whelan, Detection of ships with multi-frequency and CODAR SeaSonde HF radar systems. *Canadian Journal of Remote Sensing*, 27, 4, 277-290, 2001.

Laws, K., D.M. Fernandez and J.D. Paduan, Simulation-based evaluations of HF radar ocean current algorithms. *Journal of Oceanic Engineering*, 25, 481-491, 2001.

Paduan, J.D., D. Barrick, D. Fernandez, Z. Hallock and C. Teague, Improving the accuracy of coastal HF radar current mapping. *Hydro International*, 5, 26-29, 2001.

PRESENTATIONS:

Lipphardt, B.L., A.D. Kirwan, C.E. Grosch and J.D. Paduan, Characteristics of surface velocities in Monterey Bay from normal mode analysis. Transactions, American Geophysical Union, Vol. 82, S23, AGU Fall Meeting, December 2001.

Lipphardt, B.L., A.D. Kirwan, C.E. Grosch and J.D. Paduan, Normal mode analysis of velocity gradient fields in Monterey Bay. First Radiowave Oceanography Workshop, Timberline Lodge, Mt. Hood, OR, 9-12 April 2001.

Paduan, J.D., K. Laws and D.M. Fernandez, Effect of Stokes Drift on HF radar measurements. First Radiowave Oceanography Workshop, Timberline Lodge, Mt. Hood, OR, 9-12 April 2001.

THESIS DIRECTED:

Laws, K., "Measurements of Near Surface Ocean Currents Using HF Radar," Ph.D. Dissertation, University of California Santa Cruz, June 2001.

OTHER:

Paduan, J.D., "HF radar measurements of ocean currents," Invited seminar, Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Trieste, Italy, 12 October 2001.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction

GLOBEC MAPPING THE EVOLUTION OF MESOSCALE JETS AND EDDIES IN THE UPWELLING ECOSYSTEM OFF CAPE BLANCO, OREGON USING LONG RANGE HIGH FREQUENCY RADAR
Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The goal of this project is to demonstrate the viability of long range high frequency radar for mapping ocean currents out to 200 km from shore.

SUMMARY: This research is deploying a new application of High Frequency (HF) radar instruments for extended range coverage of filaments and eddies in the California Current System with specific application to the mesoscale jets and eddies in the upwelling system of Cape Blanco, OR in support of GLOBEC processes studies sited in that area.

PRESENTATIONS:

Cook, M.S. and J.D. Paduan, Processing HF radar data using the HFRadarmap software system. First Radiowave Oceanography Workshop, Timberline Lodge, Mt. Hood, OR, 9-12 April 2001.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Modeling and Simulation

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction

MODELING THE CENTRAL CALIFORNIA COASTAL UPWELLING SYSTEM: PHYSICS, ECOSYSTEMS AND RESOURCE MANAGEMENT
Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: National Aeronautics and Space Administration

OBJECTIVE: The goal of this project is to incorporate a multi-component ecosystem model within a circulation model of the central California coastal region.

SUMMARY: This project is modeling the oceanographic processes within the Monterey Bay National Marine Sanctuary (MBNMS) at high resolution (kms). A large body of observations is available from the region for model validation. The high-resolution coastal model will be nested within basin-scale and regional models. The model will include physical, chemical and biological properties and be capable of assimilating data from satellites and in situ sensors. The model will focus on simulating the observed strong seasonal and interannual variations in oceanographic processes. NPS scientists will participate through quality control and interpretation of physical oceanographic data sets from the Monterey Bay region.

OTHER:

Paduan, J.D., "Results from modeling and HF radar studies in Monterey Bay," SCOPE workshop, University of California Los Angeles, CA, 23-25 April 2001.

Paduan, J.D., "More Results from modeling and HF radar studies in Monterey Bay," SCOPE workshop, MBARI, Moss Landing, CA, 11-12 December 2001.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Modeling and Simulation

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction

REAL-TIME OBSERVATIONS OF A COASTAL UPWELLING EVENT USING INNOVATIVE TECHNOLOGIES
Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The goal of this project is to apply a unique suite of coastal ocean observations and models to the description and prediction of complex frontal processes.

SUMMARY: A field program was conducted in August 2000 to study the spatial and temporal evolution of a coastal upwelling front near Pt. Año Nuevo, California (20 km north of Monterey Bay). The field effort represented enhancements to the ONR Autonomous Ocean Sensing Network (AOSN) and Innovative Coastal-ocean Observing Network (ICON) programs. New observational and modeling tools and real-time data delivery were used to study the front at smaller space and time scales than has previously been possible with the scientific objective to understand how strong vertical motions impact the secondary circulations around the front. Daily aircraft overflights were used to: 1) Precisely locate the front by observing the sea surface temperature, color, and roughness; and 2) to collect a full suite of atmospheric data. Point measurements were made using a bottom-mounted ADCP from the NPS Rapid Environmental Assessment Laboratory (REAL) transmitting in real-time via acoustic modem. Remotely operated vehicles from the AOSN program mapped properties, including bioluminescence potential. A special enhanced-resolution run of the ICON nested, data assimilating circulation model was conducted to interpret and extend the measurements.

PROJECT SUMMARIES

PRESENTATIONS:

Ramp, S.R., J.D. Paduan, F.L. Bahr, R. Bluth, D. Frye, P. Koski, F. Chavez and J. Reid, Atmospheric forcing and oceanic response during late summer upwelling and relaxation events in Monterey Bay. Oceanography Society Annual Meeting, Miami, FL, 3-5 April 2001.

Ramp, S.R., J.D. Paduan, F.L. Bahr, R. Bluth, D. Frye, P. Koski, F. Chavez and J. Reid, Atmospheric forcing and oceanic response during late summer upwelling and relaxation events in Monterey Bay. Eastern Pacific Ocean Conference, Stanford Sierra Camp, Fallen Leaf Lake, CA, 23-26 September 2001.

OTHER:

Paduan, J.D., S.R. Ramp and I. Shulman, "Real-time observations and retrospective model results during MUSE." ONR Bioluminescence workshop, MBARI, Moss Landing, CA, 6-7 September 2001.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Modeling and Simulation

KEYWORDS: HF Radar, Ocean Currents, Air-Sea Interaction, Bioluminescence

MEDITERRANEAN DRIFTER ANALYSIS
Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: It is proposed to assess the water-following capabilities of commonly-used surface drifters by performing sea tests in which prototype drifters equipped with acoustic velocimeters and GPS receivers will be deployed in various wind/wave conditions.

SUMMARY: More than 500 surface drifters have been used between 1986 and 1999 to measure the sea surface circulation and temperature in the Mediterranean Sea. The velocity statistics estimated from this dataset are affected by instrumental and sampling error. The most important instrumental error is due to the action of wind/waves on the drifters, causing it to "slip" with respect to the water. Sampling errors on velocity statistics, such as the "array" bias, an important error when the lagarian data are non distributed uniformly in space, will be estimated using statistical models for the prediction of drifter trajectories. Optimized drifter deployment strategies will also be sought.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Battlespace Environments

KEYWORDS: Circulation, Lagrangian Drifers, Remote Sensing, Mediterranean Sea

MEDITERRANEAN SURFACE CIRCULATION STUDIES
Pierre-Marie Poulain, Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The spatial structure and the temporal variability of the surface circulation of the Mediterranean Sea will be studied using a comprehensive drifter data set and ancillary satellite observation.

SUMMARY: First, seasonal maps of the Mediterranean surface mean currents and eddy variability will be compiled. Lagrangian statistics (Eddy Difusivity, time and space scales) will also be estimated. Second, horizontal fluxes of momentum and heat near the surface of the Adriatic and Ionian Seas will be estimated from the drifter and satellite data. They will be related to the surface atmospheric fluxes as provided by wind products and observations. Third, the drifter data will be combined with passive remote sensing data (sea surface temperature and ocean color) to study the mesoscale circulation in selected regional areas, such

as the Adriatic Sea and the Straits of Sicily region. Finally, studies will be conducted to compare modeled and observed near-surface drifter trajectories in the Adriatic with the goal of improving future drifter deployment strategies and of assessing model capabilities.

DoD KEY TECHNOLOFY AREAS: Environmental Quality, Battlespace Environements

KEYWORDS: Circulation, Lagrangian Drifters, Remote Sensing, Mediterranean Sea

GLOBEC: MOORED CURRENT OBSERVATIONS ALONG THE EUREKA LTOP TRANSECT
Steven R. Ramp, Research Professor
Department of Oceanography
Sponsor: National Oceanic Atmospheric Agency

OBJECTIVE: The over-arching goal of the Global Ocean Ecosystems Dynamics (GLOBEC) Northeast Pacific Program (NEP) is to understand the effects of climate variability and climate change on the distribution, abundance and production of marine animals in the eastern North Pacific Ocean. The objective of the five-year Long-Term Observation Program (LTOP) moorings is to monitor the temporal and spatial variability of the currents and bottom temperature over the continental shelf off Oregon, from tidal to interannual scales, and relate this physical variability to long-term changes in the ecosystem.

SUMMARY: Oceanographic moorings to measure temperature, salinity, and velocity at the 73 m isobath 6.5 nm off the mouth of the Rouge River near Gold Beach, OR have now been maintained by NPS since May 2000. Following the loss of one instrument during the first deployment, some design changes to the hardware were made and there has been a 100% recovery rate ever since. The moorings are still in the ocean and will be recovered and redeployed again during April and October 2002. The data are being analyzed in conjunction with other moorings off Coos Bay and Newport, OR, maintained by other GLOBEC investigators. Early results indicate significant differences in the environment north (Coos Bay) and south (Rogue River) of Cape Blanco, OR, where the coastal jet separates from the coast. The physical changes apparently propagate through the ecosystem as larger numbers salmon, birds, and marine mammals were also observed south of Cape Blanco than north. Occasional onshore advection events of Columbia River Plume water have also been noted. The Principal Investigators are working with the GLOBEC biologists to understand these results. The first journal publications from the GLOBEC NEP program are targeted for the coming fiscal year.

PUBLICATIONS:

Batchelder, H., T. Strub, W. Peterson, J.A. Barth, P.M. Kosro, R. Brodeur, C. Tynan, L. Botsford, T. Powell, F. Schwing, D. Ainley, M. Ohman, T. Mackas, B. Hickey, S.R. Ramp and R. Letelier, The GLOBEC Northeast Pacific program: California current system. *Oceanography Magazine*, 2001, submitted.

PRESENTATIONS:

Ramp, S.R., P.M. Kosro, A. Huyer and T. Strub, The GLOBEC Rogue River time series. Second GLOBEC NEP Investigators Workshop, Seattle, WA, November 2000.

OTHER:

Two oceanographic research cruises per year on the R/V WECOMA off the Oregon coast.

DoD KEY TECHNOLOFY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Coastal Oceanography, Upwelling Fronts, Ecosystem Dynamics, GLOBEC

THE INNOVATIVE COASTAL-OCEAN OBSERVING NETWORK (ICON)

Steven R. Ramp, Research Professor
Jeffrey D. Paduan, Associate Professor
Curtis A. Collins, Professor
Leslie K. Rosenfeld, Associate Research Professor
Department of Oceanography
Sponsor: National Ocean Partnership Program

OBJECTIVE: The ICON objective is to develop and integrate real-time observing systems into a nested, data-assimilating model of the Monterey Bay. The system will serve as a model for future coastal ocean monitoring and prediction networks and can be transported and applied to other geographic regions of high tactical interest. The project has many partners at other institutions.

SUMAMRY: A concept demonstration is underway by a consortium of government, academic, and industrial partners to show how a diverse suite of modern, innovative ocean instrumentation can be successfully integrated into a functional, real-time ocean observation network. The plan calls for both creative application of well established observational techniques and the development of new instrumentation and algorithms, which will be utilized in the network for the very first time. Moored, single-point time series observations, remotely-sensed data, ocean acoustic tomography, and two-dimensional vector fields obtained from HF radars are being integrated into a cohesive picture of the coastal environment via a nested, high resolution numerical model. The sensor data and model output are being made available via Internet web pages for immediate application by coastal managers, defense analysts, emergency response teams, and commercial and recreational use.

PUBLICATIONS:

Shulman, I., C.-R. Wu, J.K. Lewis, J.D. Paduan, L.K. Rosenfeld, J.D. Kindle, S.R. Ramp and C.A. Collins, High resolution modeling and data assimilation in the Monterey Bay area. *Continental Shelf Research*, 2001, in press.

Ramp, S.R., D.E. Barrick, L.A. Pederson, J.C. Lee, J.D. Paduan and I. Shulman, Recent advances in coastal HF radars with potential application to the Asian marginal seas. *Proceedings, Eleventh PAMS/JECSS Workshop*, Cheju, Korea, 11-13 April 2001.

Shulman, I., J.D. Paduan, C.-R. Wu, J.K. Lewis, L.K. Rosenfeld and S.R. Ramp, High frequency radar data assimilation in the Monterey Bay. *Proceedings Seventh International Estuarine and Coastal Modeling Conference*, St. Petersburg, FL, November 2001.

PRESENTATIONS:

Rosenfeld, L.K., R. Durazo, I. Shulman, J.D. Paduan, D. Blencoe, S. Ramp and C. Collins, Comparison between modeled and measured velocity and temperature fields from an Innovative Coastal-Ocean Observing Network (ICON). Eastern Pacific Ocean Conference, Stanford Sierra Camp, Fallen Leaf Lake, CA, 23-26 September 2001.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Coastal Oceanography, Upwelling Fronts, Monitoring and Prediction, Real-time Data

PROCESSES IN MARGINAL SEAS AND ASIAEX PROJECT MANAGEMENT

Steven R. Ramp, Research Professor
Ching-Sang Chiu, Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The objective of these two closely-related projects is to plan and execute a multi-national oceanographic field program in the East and South China Seas to investigate how the complex littoral environment (i.e., its water column, boundary, sediment and sub-bottom structure and inhomogenities) affects the ray paths, mode structure, propagation loss, and temporal and spatial (both vertical and horizontal) coherence for low-to-intermediate frequency (50-4000 Hz) acoustic transmissions in shallow water. The work is part of a continuing project.

SUMMARY: Several years of advance planning and hard work came to fruition this year with the successful execution of the ASIAEX main field program during April-June 2001. The South China Sea (SCS) portion took place during April - May 2001 on the Chinese continental shelf and slope between Dongsha Island and Taiwan. The East China Sea (ECS) portion took place during May and June in the region bounded by 28-30°N and 126(30' to 128°E. Professors Ramp and Chiu were principal investigators in the SCS program, which was executed during eight cruises from three Taiwanese research vessels. Eight oceanographic moorings, eight acoustic source/receiver moorings, and numerous smaller, experimental moorings were deployed and recovered. The area was also surveyed using the SeaSoar towed undulating vehicle and a chirp sonar sub-bottom profiling system. This is the largest simultaneous, high-resolution physical oceanography and acoustic propagation data set ever collected. The data will take several years to analyze and understand. This process has just begun as of this writing.

Profs. Ramp and Chiu also serve as the International Scientific Coordinator and Assistant Coordinator respectively for both the SCS and ECS ASIAEX programs. They convened a planning workshop in Monterey, CA during December 2000, traveled to Beijing, PRC for another planning workshop in spring 2001, and convened the first post-experiment workshop in Maui, Hawaii during 29 October-2 November 2001, to begin the data exchange and analysis process.

PUBLICATIONS:

Ramp, S.R., F.L. Bahr, C.J. Ashjian and L.D. Talley, The upper-ocean circulation in the Ulleung Basin during June-July 1999. *Deep-Sea Research*, II, 2001, submitted.

Ramp, S. R., *The Asian Seas International Acoustics Experiment (ASIAEX)*, Naval Postgraduate School Technical Report, NPS-OC-01-001, 31 pp. 21-23 June 2000.

Ramp, S.R., C.S. Chiu, J.F. Lynch and P.H. Dahl, "ASIAEX Program A Huge Success!" *Naval Postgraduate School Research Newsletter*, 11, No. 3, 24-26 and 51-54, 2001.

Chiu, C.S., S.R. Ramp and J.F. Lynch, The ASIAEX 2000 preliminary experiment in the East China Sea (ECS). *Proceedings Fifth International Conference in Theoretical and Computational Acoustics*, Beijing, PRC, 2001.

PRESENTATIONS:

Ramp, S.R., Results from the Asian Seas International Acoustics Experiment (ASIAEX) environmental moorings in the South China Sea, ASIAEX Workshop, Maui, HI, October 2001.

Ramp, S.R., Physical oceanography of the South and East China Seas, COMSUBPAC/NPS Workshop, Monterey, CA, February 2001.

THESIS DIRECTED:

Rocha, J.D., "SeaWiFS Analysis of the Japan and East China Sea Air/Sea Environment," Masters Thesis, Naval Postgraduate School, December 2001.

OTHER:

In the process of transitioning new operational knowledge of the Asian marginal seas to COMPACSUBFLT in Pearl Harbor, Honolulu, HI.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Marginal Seas, Mesoscale Dynamics, Environmental Acoustics, ASIAEX

REAL-TIME OBSERVATIONS OF A COASTAL UPWELLING EVENT USING INNOVATIVE TECHNOLOGIES
Steven R. Ramp, Research Professor
Jeffrey D. Paduan, Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: The goal of this project is to apply a unique suite of coastal ocean observations and models to the description and prediction of complex frontal processes.

SUMMARY: A field program was conducted in August 2000 to study the spatial and temporal evolution of a coastal upwelling front near Pt. Año Nuevo, California (20 km north of Monterey Bay). The field effort represented enhancements to the ONR Autonomous Ocean Sensing Network (AOSN) and Innovative Coastal-ocean Observing Network (ICON) programs. New observational and modeling tools and real-time data delivery were used to study the front at smaller space and time scales than has previously been possible with the scientific objective to understand how strong vertical motions impact the secondary circulations around the front. Daily aircraft overflights were used to: 1) Precisely locate the front by observing the sea surface temperature, color, and roughness; and 2) to collect a full suite of atmospheric data. Point measurements were made using a bottom-mounted ADCP from the NPS Rapid Environmental Assessment Laboratory (REAL) transmitting in real-time via acoustic modem. Remotely operated vehicles from the AOSN program mapped properties, including bioluminescence potential. A special enhanced-resolution run of the ICON nested, data assimilating circulation model was conducted to interpret and extend the measurements.

PRESENTATIONS:

Ramp, S.R., J.D. Paduan, F.L. Bahr, R. Bluth, D. Frye, P. Koski, F. Chavez and J. Reid, Atmospheric forcing and oceanic response during late summer upwelling and relaxation events in Monterey Bay. Oceanography Society Annual Meeting, Miami, FL, 3-5 April 2001.

Ramp, S.R., J.D. Paduan, F.L. Bahr, R. Bluth, D. Frye, P. Koski, F. Chavez and J. Reid, Atmospheric forcing and oceanic response during late summer upwelling and relaxation events in Monterey Bay. Eastern Pacific Ocean Conference, Stanford Sierra Camp, Fallen Leaf Lake, CA, 23-26 September 2001.

OTHER:

Ramp, S.R., J.D. Paduan and L.K. Rosenfeld, "Physical oceanography considerations for a bioluminescence experiment." ONR Bioluminescence Workshop, MBARI, Moss Landing, CA 6-7 September 2001.

Paduan, J.D., S.R. Ramp and I. Shulman, "Real-time observations and retrospective model results during MUSE." ONR Bioluminescence Workshop, MBARI, Moss Landing, CA, 6-7 September 2001.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Modeling and Simulation

KEYWORDS: Real-time Observations, Ocean Currents, Air-Sea Interaction, Bioluminescence

IN-SITU EVALUATION OF OCEANOGRAPHIC PRODUCTS FOR THE METOC COMMUNITY
Leslie Rosenfeld, Research Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVES: i) Evaluate the Navy Meteorology and Oceanography (METOC) community's use of oceanographic products in the regional METOC centers and facilities. ii) Suggest ways in which the METOC community could improve their oceanographic support, through changes that could be made to improve the utility of their ocean products, introduction of new products, and changes in training to allow METOC personnel to take better advantage of the ocean products available to them. iii) Identify data and technology available through the academic and government research community that could be of use to the operational community. iv) Facilitate cooperation and collaboration between regional METOC centers and facilities and nearby civilian, or non-Navy government, oceanographic centers. v) Provide feedback to the Naval Postgraduate School Oceanography Department on how their graduates are faring, and what changes could be made to the curricula to help future graduates in their careers. vi) Provide on-site assistance and training in the use of oceanographic data and models.

SUMMARY: All of the Navy METOC centers and facilities were visited for periods of time ranging from two to six weeks each. Time was also spent with METOC officers and divisions on ships and staffs, and at a few detachments and components. Stops were also made at METOC production and training centers. Routine operations, fleet exercises, and actual missions were observed. Each command's classified and unclassified web sites were examined. There was extensive interaction with ocean services and fleet liaison personnel at each of the centers, as well as with the science and technology officers and Naval Oceanographic Office (NAVO) fleet representatives. Working papers were prepared on several topics of concern, including: surface wave models, the Modular Ocean Data Assimilation System, Navy operational ocean circulation and tide models, and training. Feedback was provided to NAVO and the Fleet Numerical Meteorological and Oceanographic Center on their ocean products. Connections were facilitated between the regional centers and nearby universities with physical oceanography departments, including: University of Tokyo, Old Dominion University, University of Cadiz, University of Washington, and University of Hawaii. Verbal outbriefs and written reports were delivered to each METOC center and facility Commanding Officer.

PUBLICATIONS:

Wash, C.H. and L.K. Rosenfeld, *The Role of Navy METOC Regional Centers and Facilities in the New Millennium: Thoughts from a Sabbatical Tour*, Naval Postgraduate School, Technical Report, NPS-MR-01-002, Monterey, CA, pp.14, 2001.

OTHER:

The results of this work were presented as verbal briefs to the Commander, Naval Meteorology and Oceanography Command in Bay St. Louis, MS in November 2000, and to the Oceanographer of the Navy in Washington, D.C. in December 2000.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Operational Oceanography

INVESTIGATION OF SOURCE OF HUNTINGTON BEACH SEWAGE CONTAMINATION
Leslie Rosenfeld, Research Associate Professor
Department of Oceanography
Sponsor: Orange County Sanitation District

OBJECTIVE: The goal of this project is to determine whether Orange County Sanitation District's (OCSD) ocean outfall could be the source of sewage contamination to the surf zone off Huntington Beach, California.

SUMMARY: During 2001, a field project was undertaken to determine whether OCSD's ocean outfall could be the source of bacterial contamination to the Huntington Beach surf zone. Planning activities were carried out in the early part of the year and then measurements of the nearshore circulation and water properties in the region were made during the summer. A number of institutions, agencies, and companies were involved. NPS's part involved deploying current, temperature, salinity, wind and wave measuring instruments in June and recovering them in October. All NPS instruments returned good data and initial data processing was completed in the fall. The data were submitted to SAIC which brought data from all the participants together in a common format. The complete data set was distributed to all participants in early 2002 for further analysis.

PRESENTATIONS:

Rosenfeld, L.K. et al., Field study of possible cross-shelf transport mechanisms for a treated wastewater plume discharged on the continental shelf off Huntington Beach, CA. Ocean Sciences, Honolulu, HI, 11-15 February 2002.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Coastal Circulation, Sewage Outfalls, Huntington Beach

APPLICATION OF PARALLEL OCEAN AND CLIMATE MODELS
TO DECADE/CENTURY PREDICTION
Albert J. Semtner, Professor
R. Tokmakian, Research Assistant Professor
W. Maslowski, Research Assistant Professor
J. McClean, Research Assistant Professor
Y. Zhang, Research Assistant Professor
Department of Oceanography
Sponsors: U.S. Department of Energy and Naval Postgraduate School

OBJECTIVE: To use ocean, atmosphere, and ice models developed during earlier research under the DOE CHAMMP Program in order to simulate realistic climate states using advanced parallel computers. To understand physical processes that affect oceanic predictability and climatic fluctuations or change.

SUMMARY: This five-year project is in its fourth of five years. It uses various advanced models to understand the variability of ocean and ocean-ice circulation at relatively high resolution. The NPS group collaborates with large climate modeling efforts at Los Alamos and at the National Center for Atmospheric Research. Extensive simulations were carried out last year, and analysis is underway.

PUBLICATIONS:

Maslowski, W., D.C. Marble, W. Walczowski and A.J. Semtner, On large-scale shifts in the Arctic Ocean and sea ice conditions during 1979-98, *Annals of Glaciology*, 2001, in press.

McClean, J.L., P.-M. Poulain, J.W. Pelton and M. Maltrud, Eulerian and Lagrangian statistics from surface drifters and a high resolution POP simulation in the North Atlantic. *Journal of Physical Oceanography*, 2001, accepted.

Tokmakian, R., The relationships between the low frequency signals in an ocean model and altimetry data, *Journal of Geophysical Research*, 2001, submitted.

Zhang, Y. and A.J. Semtner, The Antarctic circumpolar wave in a high-resolution ice-ocean simulation, *Annals of Glaciology*, 2001, in press.

PRESENTATIONS:

Maslowski, W., 1/12-degree pan-Arctic coupled ice-ocean model - spinup results, Climate Change Prediction Program Meeting, San Diego, CA, 1-3 October 2001.

Pierce, D.W., T.P. Barnett, W.M. Washington, A. Semtner, T. Bettge, R. Tokmakian, G. Chukkapalli, ACPI Elements 1 and 2: Initializing the coupled model from observed ocean conditions and the ensemble runs, San Francisco AGU Meeting, San Francisco, CA, December 2001.

McClean, J.L and M. Maltrud, High resolution POP, CCPP Meeting, San Diego, CA, October 2001.

Semtner, A.J. and Y. Zhang, Polar ocean circulation, variability, and anthropogenic change, as depicted in high-resolution coupled models, Gordon Conference on Polar Marine Science, Ventura, CA, 12-16 March 2001.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling, Ocean Prediction, Parallel Computing

SIMULATIONS AND RECONSTRUCTIONS OF GLOBAL OCEAN CIRCULATION WITH WELL-RESOLVED EDDIES FOR THE WOCE OBSERVATIONAL PERIOD
Albert J. Semtner, Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The goal was to further improve on the realism of numerical models of global three-dimensional ocean circulation, with important currents well depicted and to conduct simulations using the best available atmospheric forcing. The 7-year project finished in 2001.

SUMMARY: Last year, a model was developed with 2/3-degree global grid and 40 vertical levels, with improved physics, and with proper representation of coastlines and depths. The 40-year reanalysis fields of the National Centers for Environmental Prediction were prepared as forcing. Robin Tokmakian simulated conditions of 1959-98, starting from the best available climatology. A massive amount of model output was analyzed and compared with in-situ and satellite observations. Model output was provided to many requesting groups.

PUBLICATIONS:

Boening, C. and A.J. Semtner, High-resolution modelling of the thermohaline and wind-driven circulation, Chapter 2.2 of *The World Ocean Circulation Experiment*, J. Gould and J. Church, eds., Cambridge University Press, Cambridge, UK, pp. 59-77, 2001.

Tokmakian, R., The relationships between the low frequency signals in an ocean model and altimetry data, *Journal of Geophysical Research*, 2001, submitted.

Montano, R.P., E.J., Beier, P.T. Strub and R. Tokmakian, Large-scale forcing of the Agulhas variability: the seasonal cycle, *Journal of Geophysical Research*, 2001, in press.

PRESENTATIONS:

Semtner, A.J., High-resolution Global Ocean and Arctic Ocean-ice forecast systems being developed at the Naval Postgraduate School, Computing in the Atmospheric Sciences, Annecy, France, 29 October- 1 November 2001.

Tokmakian, R., Forty-plus year hindcast ocean simulation, CCPP presentation, San Diego, CA, 1 October 2001.

DoD KEY TECHNOLOGY AREA: Modeling and Simulation

KEYWORDS: Numerical Modeling, Ocean Prediction

OBSERVATION OF VELOCITY FIELDS UNDER WIND-FORCED WAVES
Timothy P. Stanton, Research Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVES: The objectives of this research are to measure and model the transfer of wind-stress through surface turbulence and waves at the air-sea interface. This momentum transfer via surface gravity waves remains poorly understood due primarily to the difficulties of measuring turbulence immediately below the wave surface.

SUMMARY: During the first year of funding on this program, prototype measurements of velocity fields below surface gravity waves were made in shallow water offshore from the NPS Marine Operations facility in Monterey Bay. A unique small scale coherent Doppler velocity profiler, the BCDVSP, was directed up under waves from a stable platform in 3.5m depth. Three component velocity profiles were measured every 1.5cm over a 1.5m range spanning the wave crest/trough region. These data sets have allowed a surface-following analysis technique to be developed to measure timeseries of vertical Reynolds stresses along with near-surface shear profiles, allowing shear production rates to be estimated. These results were presented at the fall SA and AGU meetings. Instrument developed continued for the main deployment in the summer of 2002 at the WHOI Marthas Vineyard tower.

PRESENTATIONS:

Stanton, T.P., Field observations of velocity structure directly below wind-forced waves. Waves 2001, San Francisco, CA, September 2001.

Stanton, T.P., Observations of turbulence in ocean wave boundary layers, Fall ASA Meeting, Fort Lauderdale, FL, December 2001.

PATENT:

Stanton, T.P., 2001. A Turbulence-Resolving Coherent Acoustic Sediment Flux Probe Device and Method For Using. U.S. Patent 6,262,942, issued 17 July 2001.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Wave Dissipation, Shoaling Waves, Bottom Boundary Layers

SPECTRAL WAVE DECAY DUE TO BOTTOM FRICTION ON THE INNER SHELF
Timothy P. Stanton, Research Associate Professor
E. B. Thornton, Distinguished Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVES: The objectives of this research are to directly measure wave dissipation as surface gravity waves propagate across continental shelves. Observations of dissipation in the thin oscillatory bottom boundary layer, bottom morphology and low frequency currents are being used to develop a spectral wave model of dissipation for use in shelf wave models.

SUMMARY: Analysis continued of wave forced bottom boundary layer observations made at Duck during the SHOWEX program. The Bistatic Coherent Doppler Velocity and Sediment Profiler and a scanned X/Y altimeter, both developed at NPS, were deployed at Duck, NC on an instrument frame in 12m depth allowing the response of the bottom boundary layer to a wide range of wave and currents to observed. Estimates of RMS shear and Reynolds stresses across the thin oscillatory boundary layer are being used to estimate the wave-work rate as the local bedforms evolve in response to the wave forcing. These measurements have been replicated in a coarser sediment bed, narrow-banded wave environment as a component of the long term Monterey Inner Shelf Observatory, MISO (http://www.oc.nps.navy.mil/~stanton/miso).

Two analysis techniques have been developed to estimate profiles of Reynolds stresses, shear and hence shear production of TKE. A paper describing the BCDVSP measurements of stresses in the wave and mean current boundary layers has been prepared for a SHOWEX special issue in JOAT. A paper describing the morphology measurement methods is also being submitted. A thesis project comparing bedform evolution with the DUNE2D model was completed, with preliminary results presented at the Fall AGU.

PRESENTATIONS:

Martin, S.D., E.B. Thornton and T.P. Stanton, DUNE2D modeling of vortex ripple migration, American Geophysical Union Fall Meeting, San Francisco, CA, Dececember 2000.

Stanton, T.P., Turbulent stresses and shear production in bottom boundary layers in the surf zone and inner shelf, American Geophysical Union Fall Meeting., San Francisco, CA, December 2001.

THESIS DIRECTED:

Martin, S., "Vortex Ripple Morphology Using Dune2D Model," Masters Thesis, Naval Postgraduate School, March 2001.

PATENT:

Stanton, T.P., 2001. A Turbulence-Resolving Coherent Acosutic Sediment Flux Probe Device and Method For Using. U.S. Patent 6,262,942, issued 17 July 2001.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Wave Dissipation, Shoaling Waves, Bottom Boundary Layers

UPPER OCEAN EFFECTS ON THE SURFACE HEAT BUDGET OF THE ARCTIC
Timothy P. Stanton, Research Associate Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVES: The objectives of this research are to measure the mixed layer and upper ocean heat content and heat fluxes over a one year period in the central Arctic Ocean. This work is a component of the

multidisciplinary SHEBA program which has the objectives of improving parameterizations of the coupled atmosphere-ice-ocean system in the Arctic to improve the predictive capabilities of Global Climate Models. A shorter process study focused on the role of ice keels in the surface heat balance.

SUMMARY: Between October 1997 and October 1998 the SHEBA ice camp was deployed in the Central Beaufort Sea. An automated CTD and microstructure profiler inferred turbulent fluxes from thermal microstructure measurements and the temperature/salinity structure of the upper ocean throughout a year as the ice camp drifted in response to surface wind forcing. The microstructure package was designed and built at NPS for this experiment. Analysis of the upper ocean salinity structure has revealed evidence of very significant ice melting in the last few seasons, and a paper describing this result has been published in GRL. A thesis has been completed during investigating the potential of double diffusive fluxes to net heat fluxes in areas with strong density-compensated interleaving. A paper describing the upper ocean structure and comparisons with historical data has been submitted to JGR. Techniques to improve thermal dissipation rates in the presence of strong interleaving is being developed exploiting the dual microthermistors deployed on the microstructure profiling package. This method is reducing noise levels in the vertical flux estimates which otherwise result in over-estimates of pycnocline fluxes. A unique, self contained portable ocean heat, salt and momentum flux instrument developed at NPS was deployed in an ice keel study in March 1998. This data set is being used with other SHEBA investigators to assess the role of ice keels in enhancing pycnocline entrainment.

THESIS DIREECTED:

Lamb, D.R., "Heat Fluxes Associated with Intrusions During the SHEBA Ice Station Drift," Masters Thesis, Naval Postgraduate School, September 2000.

DoD KEY TECHNOLOGY AREA: Environmental Quality

KEYWORDS: Ocean Mixed Layer, Polar Oceans, Mixed Layer Dynamics

DETERMINATION AND ANALYSIS OF MODEL/DATA COVARIANCE FIELDS FOR ASSIMILATION PURPOSES
Robin Tokmakian, Research Assistant Professor
Department of Oceanography
Sponsors: Office of Naval Research

OBJECTIVE: Short term (several months) project to examine the errors within a high resolution model which is a candidate hindcast ocean simulation for initializing ocean prediction models. Results are contained within a draft paper to be submitted in early 2002.

SUMMARY: A comparative wavelet analysis of a 0.1 degree Parallel Ocean Program (POP) simulation of the North Atlantic with coincident in situ measurements of sea surface height (SSH) and temperature is used to examine the realism of the high frequency signals (less than a year) of the surface variability. Along the coast, the analysis shows that the modeled simulated fields of SSH are very realistic with the correlations to tide gauge measurements on the order of 0.8. The wavelet spectra show that the model replicates the observations frequency space. Comparisons to temperatures made with NOAA buoys north and south of the Gulf Stream shows that, while not replicating the location of mesoscale features all the time, the model's energy in the strong mesoscale regions compares fairly well. Due to the nature of Topex/Poseidon (T/P) sampling that requires large areal averages and because of the model's spontaneous eddy field, the evaluation of the simulation is less conclusive. The model does show similarities to the T/P data at high latitudes where the sampling of the instrument is denser. Spatially, there are similarities between the model and observations of the areas where spectral bands have a dominant signal and the amplitude of that signal.

INTERANNUAL TO DECADAL OCEAN VARIABILITY AND PREDICTABILITY
Robin Tokmakian, Research Assistant Professor
Department of Oceanography
Sponsors: National Aeronautics and Space Administration

OBJECTIVE: To understand the intrinsic interannual to decadal variability of an ocean hindcast model at a resolution of 0.25 degree resolution and to evaluate the realism of that variability with respect to satellite observations. A further objective is to investigate how surface fields measured from satellites can be used to understand the variability in the subsurface layers of the ocean.

SUMMARY: Partial completion of analysis of 0.25 degree resolution ocean model and associated satellite data. Completed and submitted first of two papers related to the realism of the low frequency variability of the ocean within the model with respect to altimeter and other satellite data.

Quantitative comparisons of a 0.25 degree resolution ocean model forced with high frequency momentum, heat, and freshwater fluxes) with tide gauges and altimeter data shows the simulation produces realistic ocean circulation for large regions of the ocean. The model output is further analyzed to quantify the contribution the surface forcing makes on the low frequency variability seen in the model and altimeter data and to understand what influence the subsurface layers have on the variability of sea surface height. At low frequencies, greater than 1.5 years, only the heat flux makes significant contribution to the SSH variability, and perhaps, the Ekman pumping in a few particular areas in the Northeast Pacific, off of Nova Scotia, and in western Pacific tropical region. The influence of the steric and lower parts of the water column to the total signal is described for both the low and interannual periods. At the low frequencies, it is the dynamics within the ocean itself, rather than any local forcing that is largely determining the variability of the SSH measurements. The salinity variability, in addition to the temperature changes, also has significant influence on the SSH signal at high latitudes and in the tropical Atlantic. Last, examples are given which show how the SSH could be used to monitor the circulation of the oceans.

BEDFORM DYNAMICS AND MINE BURIAL
Edward B. Thornton, Distinguished Professor
Edith L. Gallagher, Research Assistant Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVES: The focus of the initial year of this project has been on the development of a framework for the problem and exploration of that framework with initial data sets.

SUMMARY: As a bedform migrates past a mine, the mine will fall to the low point of the bedform trough before subsequently being buried by the passage of the following bedform crest. Thus, the statistics of mine burial are determined by the statistics of bed variability and the mine burial problem reduces to a problem of understanding the time evolution of the bottom profile envelope. If we define the bottom profile as $h(x, \tau)$, and the profile envelope as spanning from $h_{min}(x, \tau)$ to $h_{max}(x, \tau)$, then mines can sink to h_{min} and can feasibly be covered at any time by an envelope thickness, $D_{max}(x, \tau) = h_{max} - h_{min}$. ($\tau$ denotes a time scale of slow evolution). When a mine is first seeded ($\tau=0$), the envelope will have zero thickness. However, as megaripples, sand bars or any other profile features form and migrate, the thickness of the profile will grow with time in a way that depends on the overlying wave and current fields. If a mine has a vertical scale W (perhaps the diameter of a cylinder), then complete burial is possible once D_{max} exceeds W. At any subsequent time, the probability of burial depends on the statistics of $D = h - h_{min}$ as the bottom fluctuates through this envelope.

PUBLICATIONS:

Gallagher, E.L., E.B. Thornton and T.P. Stanton, Sand bed roughness in the nearshore, *Journal of Geophysical Research*, submitted

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Nearshore, Waves, Surf, Currents, Morphology

MEGARIPPLES IN THE SURF-ZONE
Edward B. Thornton, Distinguished Professor
Edith Gallagher, Research Assistant Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The objective is to measure and model the development of small-scale bedforms (megaripples) in the shallow ocean.

SUMMARY: Bedforms occur frequently on barred beaches and are highly variable, both spatially and temporally. However, their distribution and variability are poorly understood. A better understanding of bedforms in the nearshore would be valuable for interpretation of sedimentary sequences in the geologic record and for estimating seafloor roughness and resulting friction factors when predicting wave energy dissipation, nearshore current generation, sediment transport, and the resulting bathymetric change. Unique observations of bedforms were made using an array of sonar altimeters mounted on an amphibious surveying vehicle. The surveying vehicle (WESP), has a large footprint (10 m), and is designed to measure the large-scale bathymetry (e.g., sand bars). The altimeters have a footprint of about 6cm and are sampled at 48 Hz. After being corrected for the motion of the vehicle on which they are mounted, they produce closely spaced profiles with vertical and cross-shore resolution of about 5 cm and alongshore resolution of about 40 cm. Thus the altimeters are capable of measuring bedforms which the large surveying vehicles cannot resolve. During COAST3D, surveys were made of a 500 x 1000 m area approximately weekly. In general, roughness is greatest in shallow water and decreases offshore. However the spatial distribution of roughness is patchy and the temporal variability is high. The observed high temporal and spatial variability in shallow water is likely owing to the variability of waves and currents, sediment grain size distributions

and the large-scale nearshore morphology. These forcing mechanisms are being investigated. In addition, these observations of seafloor roughness and its distribution will be compared for two different beaches using data acquired during the SandyDuck and COAST3D nearshore field experiments (near Duck, NC USA, September-October 1997 and Egmond aan Zee, The Netherlands, October-November 1998, respectively) to further illucidate the important forcing mechanisms for bedforms in the nearshore.

PUBLICATIONS:

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Feddersen, F. E.L. Gallagher, R.T. Guza and S. Elgar, The Drag coefficient in the nearshore, *Journal of Geophysical Research*, submitted.

Gallagher, E.L., E.B. Thornton and T.P. Stanton, Predicting large-scale bedforms in the nearshore, *Journal of Geophysical Research*, submitted, 2001.

Gallagher, E.L. and E.B. Thornton, Megaripples in the surf zone and their relation to steady flow dunes, *Marine Geology*, submitted, 2001.

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Near Shore, Waves, Surf

NEARSHORE WAVE AND SEDIMENT PROCESSES
Edward B. Thornton, Distinguished Professor
Timothy P. Stanton, Research Associate Professor
Department of Oceanography
Sponsor: Office of Naval Research

OBJECTIVE: Predict the wave-induced three-dimensional velocity field and induced sediment transport over arbitrary bathymetry in the near shore given the offshore wave conditions.

SUMMARY: Data acquired during the SandyDuck and Steep Beach nearshore experiments are being analyzed compared with models developed under this program and in collaboration with other groups. During these experiments, the vertical distributions throughout the water column of 3-component mean, wave-induced and turbulent velocities, bubbles, sediment concentrations were measured. The 3-component velocity field was measured every 5 cm over the bottom 1 m with a downward looking 1.3 MHZ bistatic coherent acoustic Doppler velocimeter (1.6 cm resolution at 48 Hz) and in the upper water column with a 300 KHz upward looking coherent bistatic acoustic Doppler velocimeter every 8 cm (8 cm resolution at 48 Hz). In addition, the vertical distribution of the horizontal velocities were measured with an array of 8 electromagnetic current meters. The small-scale morphology, which acts as hydraulic roughness for the mean flows and perturbs the velocity-sediment fields, was measured with newly developed, in-house, x-y scanning altimeter. The primary mechanism for changes in moment flux which drives the nearshore dynamics is due to the dissipation of breaking waves, the processes of which are only poorly understood. To improve our understanding of breaking waves, the dissipation associated with bubble injection and depth of bubble penetration were measured with the two acoustic systems (1.2 MHZ looking down and 300KHz looking up) and with a 3 m vertical array of 8 conductivity cells. An important component of the cross-shore sediment flux is due to the cross-shore mean flow (undertow), which is forced by wave set-up/down; the set-up was measured with an array of 8 pressure sensors. Undertow is an integral measure of the turbulent Reynold's stresses and wave radiation stresses and acts as a check for the detailed velocity measurements.

PUBLICATIONS:

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Morris, B., E.B. Thornton and A. Reniers, Nearshore wave and current predictions compared with field observations, *Proceedings Coastal Dynamics '01*, ASCE, 788-797, 2001.

Foster, D.L., T. Stanton, K. Andersen, J. Fredsoe and E. Thornton, Model-data comparisons of velocity and suspended sediment in a wave dominated environment, *Proceedings Coastal Dynamics '01*, ASCE, 751-758, 2001.

PRESENTATIONS:

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Morris, B., "Nearshore Wave and Current Dynamics," Ph.D. Dissertation, Naval Postgraduate School, September 2001

DoD KEY TECHNOLOGY AREA: Battlespace Environments

KEYWORDS: Nearshore, Waves, Surf

ACOUSTIC RANGING DURING FLEET BATTLE EXPERIMENT ECHO (FBE-E) USING THE INVERSE BETA (IB) ALGORITHM
James H. Wilson, Research Professor
Department of Oceanography
Sponsor: Naval Postgraduate School

OBJECTIVE: The primary objective is to evaluate a new methodology to use EW emissions from surface ships collected from national sensors and first relate their tracks to those generated from acoustic arrays. Then an acoustic ranging technique for passive arrays, called Inverse Beta (IB), is evaluated on FBE-E data.

SUMMARY: National sensor data, resident in the GALE Lite database, has been collected and analyzed from ships participating in FBE-E off southern California during 13-14 April 1999. Simultaneous acoustic broadband data were recorded from several Advance Deployable System (ADS) arrays. Ship tracks were constructed from the EW emissions captured in the GALE Lite database and related to the time-bearing plots generated by the acoustic data. Achievements included a nearly perfect correlation of the EW and acoustic intercepts, establishing the target range for the acoustic sensors, and identification of surface ships as military (by name) or merchant.

DoD KEY TECHNOLOGY AREA: Battlefield Environments

KEYWORDS: FBE-E, GALE Lite, Acoustic Ranging, ADS

UNDERSTANDING ANTARCTIC SEA ICE AND OCEAN INTERACTIONS USING HIGH RESOLUTION GLOBAL ICE-OCEAN MODELS
Yuxia Zhang, Research Assistant Professor
Albert J. Semtner, Professor
Department of Oceanography
Sponsor: National Science Foundation

OBJECTIVE: The overall objective is to advance the science of environmental prediction using highly parallel models of the global ocean and southern hemisphere sea ice. The variability and predictability of climatic variations as well as longer term climatic change are being examined.

SUMMARY: Considerable progress was made in simulating and understanding the "Antarctic Circumpolar Wave." The high-resolution coupled model of ocean and ice reveals subsurface aspects not previously available from limited observations in the Southern Ocean. Examination of slightly coarser resolution results from the Parallel Climate Model with an active atmosphere show correctly propagating signal of the ACW in both atmosphere and ocean -- a first for climate models. Results were published in the *Annals of Glaciology*, Vol. 33, pp. 539-544, 2001.

PUBLICATIONS:

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DoD KEY TECHNOLOGY AREAS: Modeling and Simulation, Battlespace Environments

KEYWORDS: Sea Ice, Southern Ocean, Numerical Modeling, Supercomputing

DEPARTMENT OF OCEANOGRAPHY

2001
Faculty Publications
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DEPARTMENT OF OCEANOGRAPHY

Thesis Abstracts

THESIS ABSTRACTS

VISUALIZATION AND ASSESSMENT OF GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT PROFILE DATA FOR THE PACIFIC OCEAN

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The Global Ocean Data Assimilation Experiment (GODAE) is an endeavor that will likely change the path of oceanography for many years. This attempt to assimilate, organize and provide massive quantities of widely varied oceanographic and meteorological data to the world could be a catalyst for new and innovative research opportunities. One of the data sources important to GODAE and of great possible value, the Array for Real-time Geostrophic Oceanography (ARGO), is another innovation that may lead to significant improvements in oceanographic modeling and research. The concept of thousands of autonomous floats, reporting ocean conditions to a database that can assimilate and provide this data in real or near-real time, affords countless opportunities for new methods of ocean prediction.

The true test of GODAE is to assess the utility of the data available in a real world setting, and ascertain the relative usefulness as it relates to research opportunities and operational data needs. This thesis will assess the utility of the USGODAE data server by retrieving, processing, visualizing and employing the data in observing conditions in and near the Kuroshio Current. By attempting to use the data server in a method similar to future research and operational use, an understanding of its true potential may be reached.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Computing and Software, Environmental Quality, Sensors, Surface/Under Surface Vehicles-Ships and Watercraft, Modeling and Simulation

KEYWORDS: Global Ocean Data Assimilation Experiment, GODAE, Array for Real-Time Geostrophic Oceanography, ARGO, North Atlantic Ocean Basin, Drifting Buoys, Ocean State Prediction, Climate

SWELL ACROSS THE CONTINENTAL SHELF

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The transformation of surface gravity waves propagating through shallow regions is investigated with extensive field data from the North Carolina continental shelf. A spectral energy balance equation is derived for a bi-dimensional bottom topography with random small-scale irregularities, in which bottom friction is introduced heuristically which a parameterized source term, and solved numerically using a hybrid Eulerian-Lagrangian scheme. This new model named CREST (Coupled Rays with Eulerian Source Terms) determines accurately refraction of waves by subgrid-scale depths variations using precomputed rays, allowing applications to large coastal areas with relatively coarse grids. Hindcasts of swell events during field experiments show large variations in wave heights caused by refraction and bottom friction. Widespread observations of sand ripples confirm that the bottom roughness is enhanced by wave-generated vortex ripples, thus sheltering the shore from offshore swells by dissipating wave energy in the bottom boundary layer. Resulting wave height attenuation up to 70% (84% of the wave energy) was observed in moderately energetic conditions. Bragg scattering of waves by wavelength-scale bottom features significantly increases (up to a factor two) the directional spread of waves.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Battlespace Environments

KEYWORDS: Ocean Surface Waves, Nonlinear Interactive Wave Breaking, Bottom Friction, Continental Shelf

THESIS ABSTRACTS

VALIDATION OF A STOCHASTIC BOUSSINESQ MODEL FOR WAVE SPECTRA TRANSFORMATION IN THE SURF ZONE

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This thesis presents a field validation of a stochastic, nonlinear wave shoaling model based on a third-order closure Boussinesq equations (Herbers and Burton, 1997). The model predicts the evolution of directionally spread waves propagating over an alongshore uniform beach. The model consists of a coupled set of evolution equations for the wave spectrum and bispectrum that incorporates linear shoaling and refraction effects and nonlinear energy exchanges in near-resonant triad interactions. Dissipation due to breaking is approximated using an empirical quasi-linear damping function and a relaxation to Gaussian statistics. The model was verified with field data from five alongshore instrument arrays deployed near Duck, North Carolina from August to December 1997 as part of the SandyDuck experiment. The predicted shoaling evolution of the frequency-directional wave spectra shows the expected development of harmonic peaks through triad interactions. The predicted harmonic spectral levels and direction are in good agreement with the observed spectra, but the predicted directional spread is biased low inside the surf zone. The significant wave height predictions are generally in good agreement with observations. The model tends to overshoal the waves outside the surf zone and slightly overdissipate wave energy inside the surf zone. Infragravity wave growth, sea surface skewness and asymmetry are predicted fairly accurately by the model.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Stochastic Boussinesq Wave Model, Ocean Surface Gravity Waves, Frequency-Directional Wave Spectra, Surf Zone, Wave Shoaling, Beach

IMPACT OF HIGH RESOLUTION WIND FIELDS ON COASTAL OCEAN MODELS

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The development of a coastal ocean circulation model involves many challenges, including the interaction of complex coastline and topography and the prediction of mesoscale oceanographic features. The Innovative Coastal-Ocean Observing Network (ICON) developed a Monterey Bay ocean circulation model to resolve these challenges. This study examines two different ICON model cases. The first ICON model case was forced with the 100 km NOGAPS winds while the other was forced with the 9 km COAMPS winds. The comparison demonstrated that the 9 km COAMPS-forced case produced better resolution of the ocean mesoscale. This was shown through examination of the daily sea surface temperature fields and the daily surface ocean currents. Time series of sea surface temperature showed a strong seasonal cycle. After removal of the seasonal cycle, the existence of mesoscale features was even more dramatic. A case study at Pt. Sur showed the evolution of mesoscale features associated with an upwelling event.

DoD KEY TECHNOLOGY AREAS: Sensors, Battlespace Environments, Modeling and Simulation

KEYWORDS: HF Radar, Air-Sea Interaction, Innovative Coastal-Ocean Network, ICON

ENVIRONMENTAL IMPACT ON MINE HUNTING IN THE YELLOW SEA USING THE CASS/GRAB MODEL

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The purpose of this work is to determine the necessity of a near real time ocean modeling capability such as the Naval Oceanographic Office's (NAVOCEANO) Modular Ocean Data Assimilation System (MODAS) model in shallow water (such as the Yellow Sea) mine hunting applications using the Navy's Comprehensive Acoustic Simulation System/Gaussian Ray Bundle (CASS/GRAB) model. Sound speed profiles inputted into the CASS/GRAB were calculated from observational (MOODS) and climatological (GDEM) data sets for different seasons and regions of four different bottom types (sand, gravel, mud, and rock). The CASS/GRAB model outputs were compared to the outputs from corresponding MODAS' data sets. The results of the comparisons demonstrated in many cases a significant acoustic difference between the alternate profiles. These results demonstrated that there is a need for a predictive modeling capability such as MODAS to address the Mine Warfare (MIW) needs in the Yellow Sea region. There were some weaknesses detected in the profiles the MODAS model produces in the Yellow Sea, which must be resolved before it can reliably address the MIW needs in that region.

DoD KEY TECHNOLOGY AREA: Other (Military Environmental Factor)

KEYWORDS: Modeling and Simulation, Oceanography, MODAS, MOODS, GDEM, CASS/GRAB, NIDAS

THE PHYSICAL CHARACTERISTICS OF BOTTOM SEDIMENT NEAR SUR RIDGE, CALIFORNIA

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A study was conducted to determine the relationships between the geomorphology, sedimentology, and acoustic properties surrounding Sur Ridge, California, in an effort to determine their effects on acoustic tomography. Eleven gravity cores were taken in the vicinity of Sur Ridge. Detailed acoustic and sedimentologial analyses were conducted on the sediment within each core. The acoustic characteristics of the sediment and the geomorphology of Sur slope were examined to determine their impact on the arrival times and structures of acoustic tomography signals sent from a source on Davidson Seamount to a receiver on Sur Ridge. Based on analyses of cores collected for this study, it was found that sediment along the western slope of Sur Ridge are composed primarily of hemipelagic silty clays. Sediment within the trough to the east of Sur Ridge are fine sands composed primarily of relict glauconite grains that appear to be a lag deposit created by a relatively strong bottom current. The in-situ compressional wave velocities and wet bulk densities from the cores taken along the lower part of Sur slope were then assimilated into an existing acoustic model in an attempt to improve the accuracy of the model. Results indicated that due to the presence of a sound channel in the surficial sediment, the cores taken did not penetrate deep enough into the sediment in order to obtain an accurate profile of the compressional wave velocity gradient within the sediment.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Sur Ridge, Sediment Characteristics, Acoustic Tomography, Glauconite

MINE DROP EXPERIMENT (MIDEX)
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The Navy's Impact Burial Prediction Model (IMPACT 25) determines the amount of burial a mine experiences upon impacting the marine sediment. Impact burial calculations are derived primarily from the sediment characteristics and from the mine's two-dimensional air and water phase trajectories. Accurate burial prediction requires that the model's air and water phase trajectories reasonably mimic the objects true trajectory. IMPACT 25 assumes that the objects are cylindrical in shape and calculates the air and water phase trajectories entirely from momentum equations.

In order to determine what effect a varying center of mass has on a mine's water phase trajectory, a Mine Drop Experiment was conducted. The experiment consisted of dropping three cylinders of various lengths into a pool where the trajectories were filmed from two angles. The controlled parameters were, the ratio of mine length to diameter, initial velocity, center of mass position and drop angle. Results indicate that center of mass position has the largest influence on the object's trajectory and that accurate trajectory modeling requires the inclusion of both momentum and moment equations.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Modeling and Simulation

KEYWORDS: Mine Impact Burial, Impact Burial Prediction Model (IMPACT 25)

VISUALIZATION AND FEASIBILITY ANALYSIS OF THE GLOBAL OCEAN DATA ASSIMILATION EXPERIMENT, NORTH ATLANTIC BASIN, SEPTEMBER 1999 TO MARCH 2001
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The development of the Global Ocean Data Assimilation Experiment (GODAE), its relationship to the Array for Real-time Geostrophic Oceanography (ARGO) project, and Fleet Numerical Meteorology and Oceanography Center's role in GODAE are discussed in this thesis. The drifting buoys used for data collection are described and the data available is outlined. This thesis analyses GODAE data available from the North Atlantic Ocean, collected in near-real-time from September 1, 2000 through March 8, 2001, in order to evaluate the relative success of the experiment to date and to identify the scope of possibilities for utilizing this data both at present, and once GODAE and ARGO are fully operational. The GODAE project endeavors to be a single database, serving as a collection point for worldwide oceanographic data to be utilized in ocean climate prediction. GODAE does not offer a mechanism for visualization of the data available. This thesis analyzes the data presently available through graphic representation. Visualization products include: float trajectories, temperature (T) and salinity (S) profiles, T-S diagrams, mixed layer depths and observed temperature compared to temperature climatology.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Computing and Software, Environmental Quality, Sensors, Surface/Under Surface Vehicles-Ships and Watercraft, Modeling and Simulation

KEYWORDS: Global Ocean Data Assimilation Experiment, GODAE, Array for Real-Time Geostrophic Oceanography, ARGO, North Atlantic Ocean Basin, Drifting Buoys, Ocean State Prediction, Climate

SIMULATED ANNUAL AND SEASONAL ARCTIC OCEAN AND SEA-ICE VARIABILITY FROM A HIGH RESOLUTION, COUPLED ICE-OCEAN MODEL

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The role of the Arctic Ocean in global thermohaline circulation and climate change is not well understood. High resolution, physically realistic simulations of the Arctic Ocean, calibrated and validated with observations and paleo-climate data, may provide the spatial and temporal coverage and resolution to more accurately characterize Arctic Ocean circulation, large-scale inter-ocean exchanges and allow future conditions to be projected correctly.

A 1/12-degree (~9 km) resolution coupled ice-ocean model, optimized for massively parallel computers, was developed. The model employs the latest digital bathymetry and ocean climatology available. Decades of model integration using climatological and realistic daily varying atmospheric forcing were performed.

Comparisons of model output with climatic atlases and observations indicate greatly improved representation of circulation, ocean and sea-ice characteristics, mass and property transports and water mass transformations. Areas where model physics and resolution improvements are needed are highlighted as well.

Comparison with a 1/6 degree (~18 km) ice-ocean model quantifies improvements gained from doubling model resolution. A ten-fold increase in eddy kinetic energy is seen in the 9 km model versus the 18 km model. Narrow shelf and slope boundary currents, absent in the latter, now appear and mass and property transports are closer to observed values.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Ocean Modeling, Climate Change, Ice-Ocean Interactions, Decadal Variability

VORTEX RIPPLE MORPHOLOGY USING DUNE2D MODEL

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The DUNE2D boundary layer model for small-scale morphology (Andersen, 1999) is compared with bedform morphology measured on the inner shelf in 11m water depth during the SHOWEX experiment at Duck, N.C. The model consists of inter-linked modules for flow, sediment transport and morphology. The flow module is based on solving the Reynold's averaged Navier-Stokes equations in the vertical plane with k-omega turbulence closure. The model has been extended to accept a general (but periodic) bottom boundary to be able to compare with field data. Boundary layer velocity profiles were measured using a Bistatic Coherent Doppler Velocity profiler (BCDV). A two-axis scanning sonar altimeter measured small-scale morphology over a 1 by 1.5 m area with 4 cm horizontal and 0.25 cm vertical resolutions. Bottom maps of small-scale morphology were obtained continuously every 20 minutes. A relatively simple data sequence was selected for model comparison, during which time the wave forcing evolved abruptly from Hsig~0.3m to Hsig~3.0m (bed velocity < 1 m/s), and the bed evolved from no motion (relic) to actively migrating vortex ripples. SHOWEX bedform changes under low wave plus collinear current conditions resulted in minor changes of the vortex ripple fields. Bedform migration rates of the model were similar to the field migration rates. Like the field data, the modeled data under strong forcing removed smaller scale

vortex ripples and redistributed the sediment into a larger scale ripple with a large portion of sediments in suspension above the bed. Limitations of the model owing to the 2-D assumption, periodic boundaries and monochromatic wave forcing constraints are discussed

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Waves, Bottom Boundary Layer, Nearshore Dynamics, Sediment Transport, Morphology

A FINE RESOLUTION MODEL OF THE COASTAL EASTERN BOUNDARY CURRENT SYSTEMS OFF IBERIA AND MOROCCO

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To investigate the role of wind forcing, bottom topography and thermohaline gradients on classical as well as unique features in the northern Canary Current system (NCCS), four experiments are conducted with a sigma coordinate primitive equation model. The first experiment, which investigates the pressure gradient force error, shows that velocity errors inherent in three dimensional sigma coordinate models can be successfully reduced from ~1 m/s to less than 0.5 cm/s in the NCCS. The second experiment, which investigates the effect of annual wind forcing on a flat bottom, accurately portrays classical eastern boundary current features as well as unique NCCS features associated with a large embayment (i.e., the Gulf of Cadiz), poleward spreading of Mediterranean Outflow, and the generation of Meddies. Theadditional effect of bottom topography in Experiment 3 shows that topography plays important roles in intensifying and trapping the equatorward current near the coast, in weakening the subsurface poleward current and in intensifying eddies off the capes of Iberia. The use of full instead of horizontally averaged thermohaline gradients in Experiment 4 highlights the development of the Iberian Current off the Portugal west coast, a feature not seen in the previous experiments. This shows that thermohaline gradients play an important role for the formation of the Iberian Current.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Modeling and Simulation

KEYWORDS: Primitive Equation Model, Northern Canary Current System, Currents, Meanders, Eddies, Meddies, Filaments, POM, Sigma Coordinate

NEARSHORE WAVE AND CURRENT DYNAMICS

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Mean cross-shore wave height transformation and alongshore currents observed on near-planar and barred beaches are compared with predictions based on the nearshore numerical model Delft3D. Delft3D solves the two-dimensional, depth-averaged, momentum balance (2-DH) between forcing (by breaking waves and variations in mean surface elevation), changes in momentum flux, bottom stress and lateral mixing. The observations were acquired on the near-planar California beaches at Torrey Pines and Santa Barbara and the barred beach at Duck, N.C., and include a wide range of conditions with maximum mean currents of 1.5 m/s. The model has two free parameters, a depth dependent breaking term, ? , and the bed roughness

length, s k. An empirical formula to determine ? a priori from the deep-water wave steepness and bed slope is developed, showing good agreement in the wave height transformation. Including rollers in the wave forcing results in improved predictions of the observed alongshore current structure by shifting the predicted velocity maxima shoreward and increasing the velocity in the trough of the bar compared with model predictions without rollers. On near-planar beaches and high-energy events on barred beaches, a one-dimensional (alongshore uniform bathymetry) model performs as well as 2-DH. On barred beaches under moderate conditions when alongshore non-uniform bathymetry prevails, the 2-DH model performs better than the 1-D model, particularly in the bar-trough region. Wave forcing balances the bottom stress with a second balance between alongshore variation in the mean surface elevation (pressure gradients) and the inertia of the alongshore current.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Nearshore, Waves, Surf

A COASTAL AIR-OCEAN COUPLED SYSTEM FOR THE EAST ASIAN MARGINAL SEAS

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A coastal air-ocean coupled system (CAOCS) that includes the Princeton Ocean Model (POM) as the oceanic component and the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model Fifth Generation (MM5) as the atmospheric component was developed for the East Asian Marginal Seas (EAMS) - a littoral environment that is a common operating area for the United States Navy (USN). CAOCS output verified against surface wind data from the National Centers for Environmental Prediction (NCEP) and sea surface temperature (SST)/Sea Surface Salinity (SSS) data collected from buoy stations. CAOCS output clearly shows the significance of atmospheric and oceanic mesoscale features and their associated air-sea interaction processes such as coastal upwelling, Ekman transport, and enhancement of upward vertical motion during cyclogenesis. These mesoscale features and air-sea interaction processes occur during periods prior to summer monsoon onset as well as during time periods following summer monsoon onset.

The study provides support that CAOCS does perform well in forecasting EAMS surface current circulation, SST/SSS structure, surface wind stress, and low-level atmospheric structure. Some weaknesses of CAOCS were identified that will aid in future improvement of the model.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments, Environmental Quality, Modeling and Simulation

KEYWORDS: Coastal Air-Ocean Coupled System, CAOCS, East Asian Marginal Seas, Air-Sea Interaction

A NONLINEAR WAVE SHOALING MODEL FOR ALONGSHORE VARYING BATHYMETRY

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This thesis proposes an improvement to present near-shore wave prediction models. Using weakly dispersive Boussinesq theory, the shoaling of directionally spread surface gravity waves over a beach with gentle gradients in the cross-shore and alongshore directions is examined. Following Herbers and Burton

(1997), the governing fluid flow equations are expanded to third order and depth-integrated over the water column. A resulting amplitude evolution equation for a spectrum of waves is derived, which is the main result of this paper. New terms in the higher order result include effects due to alongshore bottom slope, higher order cross-shore depth variations, and non-linear quartet interactions. The linear terms in this equation are verified by analytical methods using linear finite depth theory. Example computations for a monochromatic wave train over a plane beach quantify some of the improvements of this result over the lower order model. Opportunities for further development and verification of this result are proposed, and recommendations for application of the result in its present form are outlined.

DoD KEY TECHNOLOGY AREAS: Environmental Quality, Battlespace Environments

KEYWORDS: Ocean Surface Waves, Near-Shore Wave Prediction Modeling

PASSIVE SONAR GEOACOUSTIC INVERSION TECHNIQUE IN SHALLOW WATER USING THE INVERSE BETA METHOD AGAINST SHIPS OF OPPORTUNITY
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Electronic Intelligence (ELINT) data and broadband acoustic data were obtained during the April 1999 Fleet Battle Experiment Echo (FBE-E) in the SOCAL OPAREA. The motion of a target of interest (TOI) was reconstructed by the correlation and subsequent fusion of these data sets. This fusion resulted in a series of passively obtained range and range rate estimates for the TOI. These values were combined with the observed acoustic normal mode interference pattern (bathtub) for the TOI in order to empirically quantify the waveguide invariant (beta). Independently, a propagation model (Kraken) was run with historical geoacoustic input parameters for the region to simulate the normal mode structure of the waveguide. Furthermore, range-dependent mode-specific quantities were extracted from the model and combined with the observed interference pattern in order to establish numerical approximations for the TOI range. Subsequently, target range results from the fused data were compared to the numerical model derived range estimates.

DoD KEY TECHNOLOGY AREAS: Battlespace Environments

KEYWORDS: Shallow Water, Passive Sonar Geoacoustic Inversion Techniques, Fleet Battle Experiment Echo, FBE-E

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